

Tilburg University

From Confrontation to Coopetition in the Globalized Semiconductor Industry

van de Gevel, A.J.W.

Publication date:
2000

[Link to publication in Tilburg University Research Portal](#)

Citation for published version (APA):

van de Gevel, A. J. W. (2000). *From Confrontation to Coopetition in the Globalized Semiconductor Industry*. (FEW Research Memorandum; Vol. 792). Department of Economics.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

From Confrontation to Coopetition in the Globalized Semiconductor Industry.

A.J.W. van de Gevel.

May 29, 2000.

Preface.

This Research Memorandum is an update on Memorandum FEW 733 dated 23 July 1996. Comparing the two manuscripts next differences are striking.

First, the present paper provides the arguments as succinctly as possible. Secondly some brand new paragraphs have been included on the role of original equipment manufacturing, licensing and cross licensing, the patent paradox, the productivity paradox and the evaluation of strategic trade policy. Moreover research consortia in Japan and the European Union have been dealt with. Finally the present situation has been brought more up to date while elaborating on the positions of Europe, Japan, Taiwan, Singapore and China. Briefly, the former paper has undergone a complete restructuring.

Paper Abstract.

The silicon chip is not only a symbol of marvellous technologies that are transforming industrial production and leisure time in society, but also of trade and technology conflicts while at the same time offering the potential for cooperation.

The purpose of this paper is to show that the semiconductor industry has moved from being highly confrontational to being much more cooperative as is evidenced by the emergence of cross-national strategic alliances between companies, spanning R&D, product development, production and distribution.

Over the last 15 years the semiconductor industry has experienced startling reversals of competitive fortune in which the USA dominated in 1970s, then Japan entered in 1980s, and in 1986 surpassed the USA as the largest producer of semiconductors with most US firms abandoning DRAM production due to price competition. This reversal of market position has become known as the X-curve. Since the early 1990s the Americans are on top again but with the Koreans and the Taiwanese coming on fast. With China and perhaps India coming on line in the present decade or so, these reversals in competitiveness will continue to play themselves out in the market.

Due to external economies and spillover effects for other industries, this industry is considered to be a strategic sector, not only in the USA, where the industry came into existence, but also in Japan and Europe.

Observing the excessive returns earned initially in this industry in the USA, Japanese companies wanted to shift these profits, at least in part, to Japan, for which the Japanese government provided support.

The closing of the Japanese market both to imports and foreign direct investment undermined the initial American competitive strength.

In order to counteract the loss of competitiveness the US industry reacted, besides by restructuring, by creating, with government funding, the research consortium SEMATECH, while the American government responded by concluding since 1986 bilateral trade agreements with Japan in which Japan initially agreed to "voluntarily" restrict its exports of semiconductors and to "voluntarily" expand the imports of American chips.

In the mid-1980s Europe was a marginal player in the global competitive battle and suffered dependence on the USA and

Japan. This was a consequence of decisions taken by European firms but part also lies in the fragmentation of the European market and the policy pursued by the European governments. Europe survived through protected markets and was dependent on subsidies. The conventional wisdom was for Europe to give up on semiconductors. But this was not the situation by the end of the 1990s.

Today Europe is becoming a major force in the global information age economy. In 1998 three European semiconductor firms were in the worldwide Top 10. The European semiconductor industry shows faster growth rates than international competitors and is more profitable than the industry average. Europe is leading in the development of next generation technology and is dominant in several key global applications markets.

Japan continues to fight neck-and-neck with the USA for number one position, but their cumulative weight will progressively decrease and Asia/Pacific (Korea) may overtake Europe to become third largest chip producer.

The exorbitant high R&D cost to develop new generations of semiconductors has forced producers all of the world to form strategic alliances in order to set standards. This implies that the industry has become truly globalized. The emergence of successful global alliances has the potential to shift competition away from the current, predominantly nationalistic focus to a struggle among competing global partnerships. If relationships of this sort prosper, then at least one Japanese-American trade sore may have healed itself.

Contents.

1. Technological Characteristics: DRAMs and EPROMs.
2. Structure of the Industry.
 - 2.1. Role of Original Equipment Manufacturing.
 - 2.2. Licensing and Cross-Licensing.
 - 2.3 Patent Paradox.
3. Cost - Price Relationship and Marketing Strategies.
4. Significance of Recessions.
5. Global Competition.
6. Causes of the Decline in US Competitiveness.
7. Recovery of US competitiveness.
8. Semiconductor Trade Agreements (SCTA's) and their Evaluation.
 - 8.1. The Contents of the SCTA.
 - 8.2. Subsequent Events.
 - 8.3. Renewal of the SCTA in 1996.
 - 8.4. Evaluation of the SCTA.
9. Strategic Alliances.
10. Research Consortia.
 - 10.1. Evaluation of SEMATECH
11. The European Position.
 - 11.1. European Weakness.
 - 11.2. Forms of Protection.
 - 11.3. Unsuccessful European Strategy.

- 11.4. European Management of Dependence.
- 11.5. Technology Policy in Europe.
- 12. Evaluation of Strategic Trade Policy.
- 13. Productivity Paradox in the USA.
- 14. Present Situation and Future Global Prospects.
 - 14.1. European Position.
 - 14.2. Position of Japan.
 - 14.3. Position of Taiwan.
 - 14.4. Position of Singapore.
 - 14.5. Position of Korea.
 - 14.6. Position of China.
 - 14.7. Position of Israel.
- 15. Final Conclusions

List of abbreviations.

ASET	Association of Superadvanced Electronic Technologies
B/B ratio	Book-to-Bill ratio
DRAM	Dynamic Random Access Memory
EECA	European Electronic Components Association
EIAJ	Electronic Industry Association of Japan
EMS	Electronics-Manufacturing Services
EPROM	Erasable Programmable Read-Only Memory
FDI	Foreign Direct Investment
I300I	International 300mm Initiative
ITA	Information Technology Agreement
ITC	International Trade Committee
JESSI	Joint European Submicron Silicon Initiative
MEDEA	Micro Electronic Development for European Applications
MITI	Ministry of Trade and Industry
OBM	Original Brand Manufacture
ODM	Original Design Manufacture
OEM	Original Equipment Manufacture
RTD	Research and Technology Development
SCPA	Semiconductor Chip Protection Act
SCTA	Semiconductor Trade Agreement
SELETE	Semiconductor Leading Edge Technologies
SIA	Semiconductor Industry Association
SME	Semiconductor Manufacturing Equipment
VER	Voluntary Export Restriction
VIE	Voluntary Import Expansion
VLSI	Very Large Scale Integration
WTO	World Trade Organization

1. *Technological Characteristics: DRAMs and EPROMs.*

Semiconductors are an unseen part of our everyday life. They are intermediate goods, critical to the operation of virtually all electronics and used in the production of computers, consumer electronics, capital goods and a host of other products from automatic coffee makers, toasters, anti-lock brake systems and cellular phones to the computer. They are often referred to as "the crude oil of the information age" and will fuel our economy into the 21st century.

Semiconductors are fingernail-sized electronic circuits that process, store and move information. The technique of production involves etching of circuits on silicon wafers (a wafer is a thin, highly polished silicon crystal disk) by a combination of photographic techniques ("masking") and chemical baths, followed by baking, cutting into dice, sealing and packaging. It might be said that the information highway is paved with silicon.

For a chip to work, everything - temperature, timing, density of solutions, vibration levels, dust - must be precisely controlled. The physics of this process is not entirely understood so that manufacturing involves a trial and error process, giving rise to learning by doing. Semiconductor manufacturing today is a costly, fragmented and inefficient process that takes place in three stages: material processing, wafer fabrication, and assembly and test. The production process is a lengthy process, typically two to three months, from the beginning of chip fabrication to the sale to the final consumer.

Technological progress leads to generations with increased information storage capacity (taken as product innovation) and to production processes characterized by smaller design rules (taken as process innovations). The yield, i.e. the percentage of chips that are free from defect and thus can be sold on the market, is very low when starting production, but improves while learning.

The smaller the design rule, the more memory cells may be placed on a given area, with the effect of increasing the total number of chips of a given memory capacity on a wafer. The US was the leader in design technology, while Japan was the leader in process technology.

The improvement of performance is known as the *Law of Moore*, one of the founders of Intel, which claims that memory

capacity doubles every 18 months as a result of technological progress. Figure 1 illustrates Moore's Law. However, within a few years the generations of microchips will probably succeed each other less rapidly so that the Law of Moore might be blocked.

One way to increase productivity and lower the cost per chip, while allowing chip sizes to increase, is to increase the size (diameter) of the wafer. The semiconductor industry only recently moved from 150-mm wafers to 200-mm wafers and is now considering moving to 300-mm wafers which yield more than double the number of chips of a 200-mm wafer. Today's Pentium Pro micro-processor contains more than five million transistors.

Moving to larger wafer sizes, while imperative from a productivity standpoint, will antiquate existing manufacturing technologies and facilities. The transition to 12-inch wafers is estimated to cost equipment makers and materials suppliers more than \$21 billion.

The basic breakdown of semiconductors is into integrated circuits, which is the largest product line, discrete devices and optoelectronic devices.

Much of the international trade dispute in semiconductors centred on memory chips, in which a distinction can be made between commodity chips (DRAMs) and specialty chips (EPROMs). DRAMs, Dynamic Random Access Memories, are a volatile device. They temporarily store a large amount of data or instructions; a DRAM is a volatile chip, the memory disappears when power is turned off.

EPROMs, Erasable Programmable Read-Only Memories, are a non-volatile memory chip. They store data more permanently. In ROMs the memory content is loaded during the manufacturing stage, performing only reading operations, e.g. a fixed program in a pocket calculator.

It preserves the memory content also when power is switched off.

This distinction between DRAMs and EPROMs fits within the present trend toward commoditization and customization.

The storage capacity of DRAMs quadruples with each new generation (1K, 4K, 16K, 64K, 256K, 1M, 4M, 16M, etc.), which comes out every 3 years. In 1997 the takeover of 4 Mb DRAM by 16Mb as the mainstream product occurred and in just two years 16 Mb DRAM gave in to 64Mb which became the mainstream product in 1999. For EPROMs the storage capacity doubles with each new generation (4K, 8K, 16K etc.), which comes out every 18 months.

The DRAM market is larger than the EPROM market. Price competition is more intense in DRAMS. DRAM costs are mainly determined by current output and economies of scale. The EPROM market offers more scope for product differentiation. EPROM costs are determined mainly by cumulative output and learning by doing.

Generally, DRAMS have a lower per-bit price than EPROMs. Due to high switching costs EPROMs of older generations are still in demand even if new generations are already on the market. The demand for DRAMS is biased towards the latest generation. Access to state-of-the-art technology is critical to successful competition.

Market success for EPROMs depends on design and performance more than on low production cost.

Both large fixed costs and learning by doing imply that only a few producing firms can survive. However, continuous innovations offset this and allow small start-up firms to enter.

A key transition within DRAMS or EPROMs occurs when cost per bit becomes equivalent for adjacent generations. This leads to the demise of an old generation.

Flash memory may be considered to be a disruptive technology. It is the fastest growing and most closely watched IC product segment which is expected more than double in 2000 to \$10 billion and is forecast to account for 21 percent of the total memory market in 2000, up from 14 percent in 1999. It differs from conventional DRAM technology in that the chip retains the data even when the power is off, what is ideal for hand-held computers and digital cameras. Flash chips consume less than 5 percent of the power that a disk drive of equivalent capacity would consume. The disadvantage is that depending on the amount of memory, the cost per megabyte of flash can be between five and fifty times greater than disk memory. They can only be overwritten a few hundred thousand times before wearing out, rather than a few million times for disk drives. They are used in cellular phones, heart monitoring devices, modems and industrial robots.

Not only are unit shipments of cellular phones exploding (forecast to be 430 million units in 2000), but the amount of flash memory per cell phone is roughly doubling each year. Cell phones built in 1998 had an average of 4Mb of flash memory. By 2002, the amount of flash memory per phone is forecast to increase to 64Mb. Figure 2 illustrates this. In the early 1990s, the flash makers produced a new product format, called a *flash card*: credit card-sized devices on

which multiple flash chips were mounted which could be used like a disk drive for mass storage.

With respect to the appropriability of technology, the *basic* technique of production qua design cannot be kept secret, while the *details* of production, i.e. gaining experience, are highly appropriable. As a consequence the entry barriers with respect to design technology decrease with the diffusion of design technology through cross-licensing and personal mobility, while those for process technology increase in course of time when semiconductors achieve the high-volume status. Figure 3 illustrates the development of these entry barriers in course of time.

The demand for semiconductors is a function of the demand for the products in which they are used. Thus, it is a derived demand and it is not greatly affected by changes in chip prices. Measured in bits, demand has grown in a more or less continuous fashion while supply increases occur in large and discrete increments as producers bring new fabrication facilities (fabs) into production. Because a new fab can require up to two years and over \$1 billion in capital to construct, producers must rely on forecasts of demand when deciding whether to increase capacity. Where forecasts prove inaccurate, significant undersupply or oversupply can result.

E.g., in early 1995, the demand for SRAMs (Static RAMs) was expected to increase sharply in the near future. It was widely forecast that approximately 80% of new PCs using Intel's Pentium microprocessors would be sold with a SRAM cache memory¹. SRAM producers therefore invested in new fabs to meet

¹ A SRAM is a memory chip that requires power to hold its content with access times in the 10 to 30-nanosecond range, while DRAMs are usually above 30. A SRAM can provide a faster access speed than a DRAM and consume less power than DRAMs of comparable density but are generally more complicated and expensive to produce than DRAMs. SRAMs do not require a periodic electrical impulse to maintain the information they contain.

The term "cache" refers to a relatively small, but quickly accessible memory capacity. The cache is interim storage that is closer to the speed of the CPU. Computers with cache memory also have a main memory, which is larger, with slower accessibility. More advanced computers function most efficiently when they have cache memory in addition to main memory. A memory cache is a block of high-speed memory that helps match the speed of a fast microprocessor to a larger block of slower (less-expensive) memory. They are integrated memory units used to temporarily hold data or

the expected demand. Meanwhile, purchasers built up inventories in anticipation of a shortage, and drove SRAM prices sharply higher. By mid-1996, however, it became apparent that only about 20% of new PCs with Pentium microprocessors contained a SRAM cache memory. As new fabs came online and purchasers drew down or sold off large inventories, SRAM supply expanded and prices fell significantly.

Chip manufacturers make most of their money from just one industry, computers, and chip sales are driven by the demand for computer applications. The second largest outlet for semiconductors is consumer electronics. The other markets for semiconductors are communications, the automotive market and the defense market. In 1999 world sales of semiconductor devices amounted to \$145 billion. PC production accounts for roughly 55% of all the DRAM demand. Together with workstation and server, that percentage reached higher than 90% in 1999.

The DRAM demand is observed to grow in an echo to the release of a major PC application software. In 1988, it had a record-breaking 85% growth when DOS became the mainstream operating system (OS). The demand grew dramatically again in 1991 and 1996, when Windows 3.1 and Windows 95 were released and became popular respectively. On average, each new generation of OS pushes the DRAM demand higher to about four times of that of the previous OS. E.g., DOS requires 1Mb; Windows 3.1., 4Mb; Windows 95, 16 Mb. It is expected that Windows 98, to be widely installed in 1999, requires 64Mb and pushes the demand to another height.

The personal computer will shortly be eclipsed as the pre-eminent consumer of semiconductors, with communications and a new consumer platform taking center stage. The last few years have already seen a dramatic shift, with communications doubling its share of the chip market since 1995 to 22 percent, while PCs have dipped from over 30 percent to around 25 percent today. The communications market is fundamentally different from the computing market with diverse technologies and fragmented competition. Communications chip suppliers are more likely to use outside foundries than PC chip vendors. Moreover, since many communications circuits are built with analog or mixed-signal processes, they tend to use older

instructions that are likely to be needed for operations by the microprocessor.

process technology. There are some products which are still driven by 0.7- and 0.8-micron. This will present a challenge to chip manufacturers, since they need to adopt a broad range of processes. The emergence of a market for lagging-edge equipment can even be seen. A lot of g-line steppers are still being shipped. However, this trend will not slow down the adoption of new process technology because a number of communications circuits such as network processors, need to stay on the leading edge.

The North American market is highly dependent on the computer industry. The Japanese semiconductor market relies heavily on the consumer electronics industry. In Europe, communication systems are of relatively high importance.

A critical factor in the manufacture of leading-edge circuits is the timely availability of the best process equipment. The Semiconductor Manufacturing Equipment (SME) industry emerged in the 1970s and was at first US dominated. However, parallel to the declining competitiveness in chips have been concerns about the health of the US semiconductor manufacturing equipment industry, which saw its world market share decline from 75% in 1980 to 50% in 1992, while the Japanese share rose from 18% in 1980 to 43% in 1992. Today the worldwide equipment business is about \$25 billion annually.

The chip market is highly unstable, partly because of massive fixed costs and partly because the demand for chips can change rapidly, while a new fabrication plant can take a year or more to build. Such long lead times mean that the supply of chips tends to be sticky, that is, it does not adjust smoothly to price changes or to changes in demand.

Competition is driven by the speed of new product introduction with the result that *product life cycles* become shorter and shorter: on average, a new product generation is introduced every three to six months.

This leads to a rapid depreciation of plants and equipment and of R&D. The semiconductor industry has fallen prey to a "*scissors effect*" between rapidly increasing fixed capital costs and the requirement of an accelerated depreciation of its assets.

The result is that speed-to-market is of critical importance - a firm must be able to ramp up production quickly to competitive yields and quality. According to a McKinsey general industry study, if a company is late to market with a new product by only six months, 33 percent of the gross profit potential is lost over the product life cycle. Improving time-

to-market by one month improves profits by 11.9 percent. Time-to-market is particularly critical in high-tech markets that have been characterized as tornadoes. This dilemma of time-to-market versus better fabrication technology is the critical path challenge facing the semiconductor industry today. The consequence is a built-in tendency for an overshooting of investment relative to demand growth. The mismatches between demand and supply occur periodically and lead to price wars.

To recoup its investment, a chip firm will want to run the plant as near to full capacity as possible. It will not cut production even when demand drops, producing a glut and even lower prices. Therefore, in general prices do the adjustment to shocks, while output expands continuously. E.g., in the automobile sector quite the opposite applies.

Inherently the semiconductor industry is confronted with *boom-bust cycles*. The IC industry seems to be reinventing a historical six-year cycle of three or so up years and three or so down years. The cycle goes from strong capital spending to significant added capacity to declining average selling prices (ASPs) to reduced capital spending to little added capacity to increasing ASPs and then the cycle repeats itself. Figure 4 illustrates the industry cycle.

The cyclicalality does not originate from consumer demand, which has been growing consistently for the last 20 years, increasing according to Moore's Law. The problem is that the industry goes from undersupply to oversupply and back again. A good forecast system, not of demand but of supply could moderate this cyclicalality.

Historically, the IC producers' approach to the IC market place has been very consistent and can be summed up in one word: *overreaction*. This overreaction in good and bad times is what caused the famous boom-bust cycles in the IC industry. E.g. In 1992, the fourth year of the 1989-1992 downturn, IC producers invested only by 6 percent and this caused in part the boom years of 1993-1995. In 1996, the first year of the 1996-1998 downturn, IC producers increased MOS capacity by a record 5.9 million 200 mm wafer equivalents and this caused IC pricing to decline for three years in a row from 1996 through 1998. The 1 percent increase in MOS wafer capacity for 1999 was a record low, being less than 10 percent of that in 1996. While die shrinks and better process control are delivering more good dice per wafer, a significant capacity shortage is a strong possibility over the next 18 months. Even a year 2000 surge in IC capital spending will not be able to add

significant wafer processing capacity until mid-2001 at the earliest. Figure 5 illustrates the wafer growth slowing since 1992.

One of the explanations of the boom-bust cycles relates to the existence of *double bookings*. Double booking occurs when buyers who have been put on allocation place orders with their suppliers that exceed their real needs, just in order to assure timely delivery of the products they know for sure they do need. Clients are scared of not being able to secure enough products and are willing to order 20 to 50 percent more than they need. The logic behind double booking seems to be based on the notion that humans extrapolate to form projections about their future needs. The players include the OEMs that manufacture the equipment and the IC vendors and they are impacting each other, horizontally and vertically, with their own forecasts.

The main problem is that the forecasts are biased because humans are poor anticipators of changes in direction; they extrapolate the most recent trend into the future, ignoring most previous oscillations. Extrapolation of the present into the future assures that the projections will miss the key turning point and that the industry continues full speed ahead without cycles. Often unnoticed is a mild reduction in demand which causes a buildup of inventory in the channels. Only after facing cancellations of larger orders coupled with returns in significant quantities OEMs realise that the party is over. As usual, the process continues down the supply chain ending with an industry recession. As soon as a slowdown begins, prices drop, demands (in units) declines, inventories explode and capacity is underutilized.

This forecasting-via-extrapolation concept prevents management from realizing changes in demand until it is too late. Historically, it seems to take IC management 4 to 6 months to accept that a peak has occurred and during this period most decisions are already made in the wrong direction.

The semiconductor industry seems to be among the few manufacturing industries that allow the practice of "selling insurance" i.e. allowing double bookings while not charging any premiums for this insurance, i.e. penalties for cancellations. Buyers can place orders for huge quantities of chips or capital equipment, knowing that canceling part or all will not trigger a penalty.

If penalties for cancellations would be enforced, clients will not place new orders for ten years is the common reaction to

change the status quo.

Nevertheless, if suppliers are to charge penalties for cancellations in their purchase agreements, a significant improvement in the negative impact of double bookings may be expected in the future.

The cycle time consumed from the start of silicon processing to the end of the assembly-and-test process is between three to six months. This cycle time imposes severe cash flow problems because of large work-in-process costs. In addition, such cycle times mean that production planning must be based on demand forecast, not actual orders.

Adding production capacity by building a new fab takes about two years from initial conception and must run full flow for up to 10 years to pay for itself. In a market where visibility is that short and adding capacity takes that long, going through cycles of overcapacity is inevitable, no matter how much demand grows.

Historically the cycles have been very predictable. When possible, it makes the most sense to build a new fab during the bust, so it is ready for full-blown production right when the market is starting a boom period. Unfortunately, this would require spending hundreds of millions of dollars at a time when the market is down.

Normally it is considered prudent to wait for the market to be up for a number of months before committing to an expensive new fab project. However, this limits the time that the new fab can be used to take advantage of that up market. The advantage to starting a new fab project when the market is down, is only available to firms that can afford to do so. One of the safety valves to protect against undercapacity for the companies that wait are the foundries which become second-source fabs either for traditional semiconductor companies or dedicated to particular customers. Foundries should be taken into account when evaluating overcapacity.

The tendency in the market is to overreact in both phases of the cycle. Companies tend to add too much capacity in the boom periods and cut back too much capacity in the bust periods. This deepens the boom-bust cycle. Most of the reason for a downturn in the semiconductor industry is overcapacity. Overcapacity has driven DRAM prices downward, even though demand for memory has continued to grow at nearly 75% per year.

The semiconductor industry is characterized by high fixed-costs and patent races. To remain competitive firms must

continuously invest a significant share of revenues in R&D and new plant and equipment. In the USA it is common to allocate more than 30% of sales and revenue to R&D and capital expenditures. R&D expenditures as a percent of sales were fairly constant (12-14% between 1990 and 1994) for US merchant manufacturers, while capital expenditures have risen to unprecedented levels; in 1994 capital expenditures amounted to 17% to total sales after ranging between 10-12% in the previous four years. The ratio of capital expenditures is the highest among the industries for which data are available and exceeds the next highest industries (5% for steel and pharmaceuticals) by a factor of 3.4. The semiconductor R&D ratio is exceeded only by pharmaceuticals and matched by software, what is unsurprising since these industries are characterized by patents and intellectual property rights, which provide incentives for investment in R&D.

Financial performance in the semiconductor industry tends to be highly cyclical. Since 1978 there have been four expansionary cycles in which worldwide revenues grew at rates in excess of 25% per year. Each of these boom periods was 4 to 6 years in length. In periods of troughs sales revenues either declined or stagnated.

Profits as a percent of sales have been strong during boom periods; in each of the past three expansionary periods, the pre-tax income has averaged about 10% of sales revenues. In 1993 and 1994, financial performance was outstanding with 20% pre-tax income of sales. In 1994 the profit margin for semiconductors is exceeded only by that of pharmaceuticals and some financial institutions.

Recently a consistently large difference has been identified between the 21-year average worldwide semiconductor industry growth rate (17%) and the actual individual yearly figures. As shown in figure 6, each year from 1978 through 1998 the worldwide semiconductor industry either grew 24 percent or more, or 10 percent or less. Never in this 21-year period did the worldwide semiconductor industry grow between 10-24 percent (\pm points from the average). It is ironic that 1999, the year immediately after this long-term trend was revealed, registered the first exception to the trend in more than 20 years. In 2000, the worldwide semiconductor industry is forecast to increase 23 percent. If this occurs, industry growth will be more in line with the historical trends. However, the market rarely behaves exactly as expected.

At present semiconductor equipment suppliers must speed up the delivery time and ramp-to-performance of their gear to satisfy

the shorter design cycles of their chip customers. The technology cycles have shrunk over the last 10 years from three and half years to two years and sometimes even less than two years rendering older chips obsolete. Chip makers need their equipment vendors to respond more quickly. Normally one sees stretching out and then shrinking in, but lead times never get on average less than six to nine months, what is too long compared to the life cycles of the technology. By the time the equipment is installed and running, a full year can pass before wafers start coming out of the end of the pipe.

In this respect a variable that comes into play is the specter of 300 mm technology. Building one of the first 300 mm fabs may be too risky and building one of the last 200 mm fabs may be committing to a facility that will become too obsolete to pay for itself. It is very possible that many companies will postpone adding to their own capacity and this may lead to an undercapacity situation, raise IC prices and set up the next boom period. Unfortunately, these companies then build enough new fabs just in time to set up the next overcapacity condition.

A key problem burdening the industry's equipment supplier/device manufacturer interdependence is the continuous shifting of responsibility for technical advances taking place to key equipment suppliers. In past wafer size transitions, chip producers shared risk and development costs with equipment manufacturers, along with development of key technologies at Bell Labs, NTT and IBM's research labs. However, in the 200 to 300 mm transition, being not simply a scaling effort but involving fundamental technology shifts, semiconductor manufacturers dedicate R&D dollars almost exclusively to IC design, process integration, yield enhancement, etc, leaving the bulk of the 300 mm R&D burden to wafer fab equipment suppliers. From 1993 to 1997 equipment industry R&D spending has surged by 30% per year and could reach \$3.6 billion per by 2000 and \$4.3 billion by 2001.

A promising new technology may be to manufacture spherical silicon semiconductors replacing traditional rectangular chips, allowing the entire surface of the sphere to be used for circuitry unlike flat wafer processing where some parts are wasted. The advantage is that there is no need to build traditional and costly cleanrooms. Moreover it offers the potential of equipment and process stability across several generations of technology so that the enormous capital infusions every few years for new processes and equipments to accommodate more complex systems and larger wafer sizes may be

avoided. The first commercially viable product will probably be manufactured in 2000.

On January 19, 2000, Transmeta, a notoriously secretive firm based in Santa Clara, California, unveiled a new kind of microchip. The immediate benefit is a microprocessor that can run software written for Intel's chips, while consuming a fraction of the power. It is considered to be the first truly innovative development in processors in the last 12 years. Although microprocessors have continued to improve in performance over the past few years, there was a price to be paid: millions of transistors were needed to pull these tricks off, so that the modern x86 chips were large and power-hungry, which was bad news for users of portable computers.

Transmeta's chips operate in a fundamentally new way, allowing them to emulate any existing microprocessor without the loss of performance normally associated with such emulation. The new chip is specifically designed to execute micro-operations quickly and efficiently: it maximizes battery life while optimizing performance. In technical terms, a special layer of "code-morphing" software that sits between the chip and the x86 program fools the program into thinking that it is running on a standard x86-compatible processor.

The advantage is that far more complex kinds of optimisation are possible. By translating a particular chunk of x86 code into micro-ops it can store the translated chunk in a special memory to avoid having to translate it again as has to be done by using hardware. The immediate benefit of all this trickery is to reduce power consumption. People are tired of their batteries running out, tired of shoulder burn from heavy laptops. Transmeta's Crusoe TM5400 chip, which is intended for use in laptop computers, has a performance comparable with a mobile Pentium III, but contains a quarter of the number of logic transistors and consumes a twentieth of the power. In effect, the Crusoe is a silicon chameleon, allowing one computer to run not only Windows but also Macintosh programs and Sony PlayStation games. Transmeta chips can be upgraded with software to remain on the cutting edge for years with simple keystrokes so that no longer road warriors have to keep buying new laptops to get the latest gee-whiz features.

Transmeta has so far declined to take on Intel on its home ground, but ultra-light laptops are the fastest-growing part of the PC market and that is a nice niche market for the Transmeta chip in the coming post-desktop era. The first version of the Crusoe processor is targeted at mobile Internet

devices operating with the Mobile Linux OS and will be available in the first half of 2000. Its radical approach looks likely to have a profound influence on the future course of the industry.

2. Structure of the Industry.

A widely used classification of the semiconductor industry differentiates between firms manufacturing standard products sold to many different users and customer-specific devices manufactured for one end-user only.

Until just a few years ago, US and European firms deemphasized commodity products on which competition from Japan and South Korea was strong, in favour of high-integration, design-intensive products.

Another basic distinction in the semiconductor industry is between captive and merchant firms. Captive firms (IBM), are vertically integrated and consume the chips they produce, having little influence on prices. As purchasers on the market they desire low prices.

Merchants firms (Motorola) produce for sale. They reap gains from maintaining high prices and they benefit from protection. The US industry is largely composed of merchants, while Japanese producers are largely vertically integrated in "keiretsu".

Nowadays the chip industry is shifting from a vertically integrated single-nation based industry to a horizontally integrated, cooperative industry based on multinational partnerships and alliances.

Over time firms have progressively integrated their erstwhile standalone operations in individual host countries into increasingly complex international production networks: they have broken down the value chain into discrete functions and located them wherever they could be carried out most effectively and where they were needed to facilitate the penetration of important growth markets. Reduction of costs was one important motivation. Of equal importance was access to clusters of specialized capabilities and contested growth markets and the need to speed up response time to technological change and to changing market requirements. The result is that an increasing share of the value-added shifts across the boundaries of the firms as well as across national borders.

Not long ago, some contract manufacturers did little more than plain-vanilla assembly. But now, in addition to manufacturing,

these electronics-manufacturing services (EMS) companies can provide design, distribution, even customer services. Outsourcing is not really contract manufacturing anymore. That was the old model. It is EMS. It is a very broad range of services: everything from designing the chips to the product to the supply chain to the manufacturing to the testing to the aftermarket support and repair. A company outsources just about everything it can, from foundry work through assembly to inventory management and even testing. A company might get its products designed by one enterprise, its silicon provided by another, the assembly handled by a third, integration and packaging by a fourth and so on. The host or brand company basically is responsible for some R&D, marketing and demand generation.

There is seemingly no end to the degree to which name-brand electronics manufacturers want to outsource to reduce costs. Offloading all or part of manufacturing has freed the brand-name equipment makers to focus on research and development, marketing and sales and has led to huge growth among the contract manufacturers. It is all about R&D and marketing these days, someone else has to handle all the rest. E.g., IBM is outsourcing but keeps the supply chain in terms of supply and technology in its own hands. IBMs manufacturing campus employs more than 7000 workers, but fewer than 1500 are actual IBM employees. That's because IBM uses a number of other companies to perform certain manufacturing tasks, such as cable assembly, enclosures, and subassemblies.

The supply chains have changed more in the past three years than in the prior 30. The industry has gone from monogamous relationships to a swinging sixties multiple partners model. Wall Street loves it. The talk today is of leveraged supply chains.

This trend of outsourcing both within the nation and across countries is manifest in different directions:

- * Upstream wafer fabrication ("front-end") is increasingly performed by foundries for another microchip supplier.
- * Downstream, "back-end" assembly and test operations can also be outsourced.
- * A new type of advanced chip supplier is the design-focused fabless house which does not produce wafers. Design-ins refer to the practice of designing semiconductor devices for specific commercial products.

Currently, companies are outsourcing the equivalent of just 10% to 15% of the total cost of all electronics goods sold and in the next few years this figure could rise to 50% and even

75%.

At present the foundry industry is experiencing a boom that will continue well into the present decade. With the convergence of the technology roadmap at the 0.25 micron level in 1998 the foundry business suddenly and fundamentally changed. With that convergence the foundries became providers of industry-leading technology so that every start-up has access to cutting-edge silicon performance and density. This had been leveled the playing field for the industry.

But there is more to a game than just a level playing field. Designers who want to play the leading-edge game find themselves increasingly in need of leading-edge help, in the form of design, packaging and test services. Not every foundry can answer that call. But the leading foundries with the ability to leverage the latest products and best practices of the leading equipment and materials manufacturers have moved well ahead of the rest. These foundries have seen that the name of the game is not just about processes and technology, but also about integrating world-class intellectual property and tools into their business flows. These foundries have built relationships with electronic design automation houses, library vendors, IP developers and back-end packaging and test houses to help them deliver the services designers need.

Today, the state-of-the-art foundries grant designers the freedom to choose the best new place-and-route engine or functional block or library. Even before the emerging standardized processes become commercially available, designers have access to a wide array of best-of-class services. Therefore, the ability to deliver leading-edge technology and to leverage the latest services has opened the door of system-on-chip design to the global community.

By 2010, foundries are expected to produce more than 45 percent of all wafers and will support 40-50 percent of total semiconductor industry revenue.

This foundry growth is driven by four factors.

1) The explosive growth of the wireless and broadband communications infrastructure requires increasing complex ICs. Therefore, device manufacturers are investing more money in their core competencies (design and IP) and are outsourcing manufacturing to the foundries.

2) These emerging applications are enabled by ICs that exploit the latest process technologies and foundries can supply this technology cost-effectively, creating economies of scale by pooling the demand of hundreds of customers. In the past

foundries were as much as two or three generations behind the leading device manufacturers but now they have closed that gap.

3) The cost of building new fabs is becoming increasingly prohibitive for all but a very few companies. A 300mm fab will soon cost \$2.5 billion. The foundry business model, by pooling demand, will allow these mega-factories to ramp to profitable volume at an accelerated rate.

4) Foundries offer increasingly competitive customer service through value-added design, testing etc., which were previously only found at the internal facilities of an integrated device manufacturer.

These factors explain why the demand for pure-play foundry services is skyrocketing. They are capable to satisfy the customer requirements of demand fulfillment, fast turnaround, leading-edge process technology, high and stable yields and a strong service record.

In this respect a cluster model has gained importance where fabs are constructed next to each other to take advantage of economies of scale and of engineering knowledge such as in Hsinchu (Taiwan), Singapore and the state of Washington. Taiwan's foundry industry has been the world's leader since 1995 and many overseas as well as domestic device manufacturers are eagerly participating in foundry business.

Measured by cost of goods sold, probably 10 cents out of every dollar in the manufacturing of electronics products involves contract manufacturers. The silicon foundry business is expected to grow from \$7 billion in revenues to \$36 billion in 2004 as more integrated device manufacturers opt to outsource chip production. This growth will reshape the future of semiconductor manufacturing and strategic outsourcing will become a long-term solution to the cost penalties of in-house fabrication.

Currently, foundries produce about 12% of the semiconductors in the world, and by 2004 that share will more than double to 26%. The Big Three pure-play foundries (Taiwan Semiconductor Manufacturing, United Microelectronics Corp. and Chartered Semiconductor Manufacturing) collectively account for 69% of today's silicon foundry volume, but their share is expected to grow to 88% by 2004.

Behind the move of original equipment manufacturers (OEMs) seeking to offload their production woes (e.g. in terms of inventory management) lies something of a *financial paradox*. Wall Street apparently has become wary of manufacturing

concerns, fearful that they cannot achieve an adequate return on their capital. Therefore, to remain cost competitive companies are being forced to outsource driven by Wall Street. Yet investors do not seem concerned when those same assets turn up on contract manufacturers' balance sheets, as is witnessed by the contrasting stock market performance of OEMs and subcontractors.

The move toward the fabless model by outsourcing to foundries, which will result in fewer integrated device manufacturers, may help a lot to mitigate the cyclical nature of the semiconductor industry. The remaining integrated device manufacturers will have more scale, more capability to do incremental fab additions, more structure and large markets to serve. They will know more about what is going on in the markets they serve and have the necessary critical mass to grow in a more controlled manner.

To take an example, let's say there is demand for more devices and there are, say, eight relatively small companies which all build a fab. Since they are not large companies, they don't know whether they can fill the fab and may make a billion-dollar mistake. However, a major foundry might be able to meet the needs of those eight fab companies by building only three new fabs instead of eight fabs. This more moderate fab growth could reduce the oversupply problem. Therefore, as companies continue going fabless the industry might become less cyclical.

To date foundry companies can be classified into two groups: the dedicated foundry companies mostly located in the Asia-Pacific region and the integrated device manufacturers with a foundry business line which are mainly American or Japanese companies. Figure 7 shows the global foundry players.

However, scattering production around the globe has its drawbacks. A question for OEM strategists is often whether shipping costs offset the cheapness of labor overseas, particularly Asia. For some, the promised savings vanish when they have to employ batteries of phone clerks in the OEM headquarters to track orders lost or stuck somewhere along the global supply chain. Therefore, the emerging strategy is for firms to place much of the manufacturing close to their end markets. Increasingly, the fabrication and cutting of wafers along with the assembling and testing of finished goods all occurs within a particular region, depending on the end market. By adopting a regional approach, OEMs can cut both their time to market and their inventories.

There are a few constraints to the growth of outsourcing.

- 1) Execution is not the least of them. Sustaining high growth rates is famously difficult. In the race to become the biggest, most global, most diverse electronics-manufacturing provider, a company could spread itself too thin and fail to provide enough customer attention and responsiveness, so that clients will jump to smaller companies.
- 2) Not every OEM has wholeheartedly embraced the outsourcing model. Some companies worry about becoming overly reliant on outsiders. Overdependence on a contract manufacturer can be a problem. Confidentiality is a problem too.
- 3) Choosing a contract manufacturer can be a perilous decision. Contract manufacturers cannot always meet the demands of their clients. Every time they pick a provider, they bet their business, because if they pick the wrong provider and if they cannot get their product to market at the right quality, at the right time, they don't have a business.

Risks aside, the movement toward outsourcing is gathering strength. If electronics production shifts to the contract manufacturers as expected, their clients may one day wake up to find that the servants have become richer than their masters.

The conclusion may be that foundries have an ever-growing presence, with leading-edge technologies and an increasing demand for their services. OEMs dream of finding a contractor with sufficient versatility and skill to take a design, produce the early samples, build up volume, distribute into key markets and then ensure that the OEM does not get billed for piles of obsolete inventory.

However, contract manufacturers operate on razor-thin margins, often as little as 3.5% of sales. As some point out, contract manufacturers could face problems similar to those that drove the OEMs out of manufacturing in the first place. As the cliché goes: The more things change, the more they stay the same.

2.1. The Role of Original Equipment Manufacturing.

Original Equipment Manufacturing (OEM) has played an important role in the development of East Asian latecomers in the semiconductor industry.

OEM is a specific form of subcontracting, under which a latecomer supplier produces a finished product to the precise specification of a foreign TNC. The foreign firm then markets the product under its own brand name using its own

distribution channels, enabling the latecomer to circumvent the need for investing in marketing and distribution. OEM evolved out of the joint operations of buyers and latecomer suppliers and became the most important channel for export marketing in East Asia during the 1980s. OEM often involves the foreign partner in the selection of capital equipment and the training of managers, engineers and technicians as well as advice on production, financing and management. In South Korea, OEM is sometimes linked to licensing deals. Successful OEM arrangements often involve a close long-term technological relationship between partner companies, because the TNC depends on the quality, delivery and price of the final output. The outsourcing of (part of) the production process to another company has been the prime transaction, rather than the possible knowledge transfer.

The term OEM originated in the 1950s among computer makers who used subcontractors (called the OEM) to assemble equipment for them. Under early forms of OEM, the latecomer performed only value-added related to assembly services. In the 1960s it was adopted by US chip companies who used OEMs to assemble and test semiconductors for them. Since then the term has acquired a variety of meanings.

In 1988 and 1989 this system began to be called Own Design and Manufacture (ODM) in Taiwan. Under the ODM the latecomer carries out some or all of the product design and process tasks needed to produce a good according to a general design layout supplied by the foreign buyer or TNC, while still avoiding the risk of launching own-brand products and the costs of investing in foreign marketing and distribution channels. ODM indicates an advance in technological competence relative to OEM, although it applied mainly to incremental (follower) design, rather than leadership product innovations based on R&D.

The OEM/ODM system has several disadvantages. Strategically, the latecomer is often subordinated to the decisions of the foreign company and dependent on it for technological and components as well as market channels. The TNC will often impose restrictions on the sales activities of latecomer suppliers. Without their own distribution outlets, the post-manufacturing value-added is limited. Moreover, OEM and ODM make it difficult for local companies to build up the international brand images needed for high quality goods.

Despite the problems inherent with OEM/ODM, it would be wrong to understate the importance of the system. It facilitated rapid industrial growth in electronics and permitted the

assimilation of technology. In some cases the more restrictive clauses on OEM and licensing could be renegotiated. E.g., marketing restrictions on mature products have often been set aside so that South Korean firms could sell directly into third countries. The system allowed many companies to achieve economies of scale in production and, in some cases, justified investments in automation technology. For their part, foreign TNCs continued to benefit from low-cost capacity expansion, enabling rival TNCs to compete with each other. OEM/ODM therefore endured a mutually valued arrangement.

Sometimes there was progression from OEM to ODM to OBM (Own-Brand Manufacture). OBM occurs where the firm sells goods under its own brand name, capturing more of the post-production added value. Then capabilities are learned with respect to technology, organization, management and marketing. In course of time the importance of OEM contracts as a source of technological upgrading has decreased because many firms have by now accumulated substantial knowledge about product design, quality control systems as well as managerial practices. E.g., for Samsung the disadvantages outweigh the benefits gained from OEM business, so that it minimizes the importance of OEM contracts. Daewoo Electronics is known to be heavily dependent on OEM sales.

It may be concluded that OEM contracts have served as an important source to upgrade the technological capabilities of the Korean and Taiwanese firms. OEM also played a crucial role in the development of the electronics industry in Singapore and Hong Kong.

2.2. Licensing and Cross-Licensing.

Patents and trade secrets have become a key element of competition in high tech industries. In general, fierce competition has put a premium on innovation and on defending intellectual property (IP) from unlicensed imitators. In the semiconductor industry licensing and cross-licensing of IP has become a significant dimension of competition. It involves the sale or exchange of property rights and gives companies reciprocal access to the technology of other companies without risking patent interference.

Because the range of technology is too great for a single firm to develop its entire needs internally, a firm competing with advanced products and processes is likely to utilize not only its own technologies, but also the patents of others. Firms will need to cross-license patents from others to ensure that

they have freedom to manufacture without being sued for infringement.

Developing a valuable patent portfolio is increasingly important because patents provide not only protection from imitation, but they provide bargaining chips in negotiating access to other firm's technology and they may be an additional source of earnings. The value of a portfolio is greatest when it has a high proportion of high-quality patents that cover significant product markets. Most likely the firm is to create valuable IP where it is actively involved in the market, i.e. in its core business. In developing its patent portfolio the firm should not focus on those technological areas where its cross-licensee is strongest in an attempt to duplicate or avoid the licensee's patents.

An important dimension of cross-licensing is the calculation of balancing royalty payments according to the relative value of the patent portfolios of each party. Each firm's IP contribution is evaluated by estimating the value of a firm's patent portfolio to its licensing partner, with the net royalty payments to the one with the greater contribution. Therefore, the key to successful cross-licensing is a portfolio of quality patents that covers large areas of the partner's product markets. The increasing importance of IP has spurred intellectual capital management from the mere licensing of residual technology of the past to a central element in technology strategy. At present new entrants and incumbents are not only protecting their IP but are increasingly exploiting it.

2.3. Patent Paradox.

In the USA in 1984 the Semiconductor Chip Protection Act (SCPA) established protection from copying the design of semiconductor manufacturing. This Act aimed at improving the ability of semiconductor firms to prevent unauthorized copying and use of their semiconductor layout designs, e.g. by making it more difficult to challenge a patent's validity and by increasing the penalties on infringers through awarding higher damage in patent disputes.

Its economic significance appears to be limited since only one case has ever been litigated under its provisions. This may be due to the increasing complexity of manufacturing process technologies. Copying of a design device is necessary but not sufficient to enable large-scale production of infringing products.

In the fabless segment of the industry in which contracts with other firms are required because of the extensive reuse of design data the SCPA has facilitated the licensing process.

Despite the legal strengthening of the enforceability of US patent rights, evidence suggests that US manufacturing firms rely more heavily on secrecy and lead time to recoup their R&D investments than they do on legal mechanisms such as patents.

Since the early 1980s the effectiveness of patents as a means of appropriating R&D returns has declined. However, this decline has coincided with a recent and unprecedented surge in the overall number of US patents applied for and granted to firms each year. The propensity of semiconductor firms to patent has risen dramatically. Around 1986 a rather steep rise occurred in the patent applications obtained per million dollars of real R&D spending in the semiconductor industry. Patenting per million 1992 real R&D dollars in the semiconductor industry doubled between 1982 and 1992 from about 0.3 to 0.6. In the semiconductor industry this gap between the relative ineffectiveness of patents and their widespread use is particularly striking.

The question is why are semiconductor firms patenting so aggressively while they do not rely heavily on patents to recoup their R&D investments?

Patents still perform their traditional function of safeguarding against outright theft and infringement and imitation of inventions. However, this classical role of patents seems to be dominated by a broader use of patents as "legal bargaining chips". This enables firms to avoid being excluded in a particular field of use, to obtain more favorable terms of their licensing agreements with other patent owners, to gain access to external technologies on more favorable terms of trade and to safeguard against costly patent litigation.

Since a single firm rarely owns all the rights to technologies embodied in a new product it is important to have assets with which to trade in the event that other patent owners assert their rights against the firm.

Because of the short product life cycles in this industry and the fact that competitive advantage is largely driven by lead time, design complexity and superior manufacturing capabilities, patents are a relatively ineffective means by which to profit from inventions, at least for current-generation products. In the US it takes 18 months on average for a patent to issue, while the average life cycle of semiconductor products ranges from a year to 16 months.

Successor generations of products may incorporate the older technology embodied in the patent, but even this period might last 4-6 years, which is far less than the 20 year life of the patent. Nevertheless, the longer-term value of patents can remain quite high if future generations of products build on the widely used patented technology and alternative methods are difficult or prohibitively costly to adopt.

Therefore, manufacturers are clearly ramping up their patent portfolios and harvesting their latent inventions to add to their stock of issued patents. There appears to be a "race to patent" not to win rights to some standalone technological prize, but a race to create patents as bargaining chips in negotiations with other patent owners to secure the right to exclude others before being excluded themselves.

3. Cost - Price Relationship and Marketing Strategies.

In the electronics industry products seldom wear out before becoming obsolete. The economic consequences of approaching technical barriers will be felt before the technological barriers are reached. E.g., the costs of achieving higher levels of chip performance rise very rapidly as the limits of a manufacturing technology are approached and then surpassed. Figure 8 illustrates this point. Technology barriers, T_1 and T_2 , are where minute increases in chip performance can be achieved only at a huge cost. Economic barriers occur where increasing costs drive prices beyond the maximum price buyers are willing to pay, (at E_1 and E_2), causing the market to stagnate before the technological barriers are encountered.

Eventually, as a new manufacturing technology takes hold, the industry jumps from a cost-performance curve associated with the old technology to a new curve for the new process. When this happens, higher levels of performance are obtainable, shifting the barriers to E_2 and T_2 . This prompts buyers to replace older equipment.

Several sorts of scale economies are prominent in semiconductor production:

- * *Static* scale economies: the costs of building a chip facility and the R&D cost are incurred once before production begins and are then averaged over all chips produced, so that the larger the production, the smaller the average costs.
- * *Dynamic* scale economies: they are cumulatively experienced as long as more chips are produced because failure rates fall.
- * *Dynamic* scale economies: they extend across generations of chips. Producing one type of chip enhances the ability of

firms to develop and produce future generations of chips. All these scale economies are *internal* to the individual chip producer: they depend on what that producer does. There are also scale economies *external* to the individual chip producer. Semiconductors are intermediate goods so that the production process of chips generates valuable knowledge useful to other chip producers and to developers of products that use chips. Due to these spillover effects the semiconductor industry is considered to be a strategic sector, deserving governmental support.

In DRAMs there are several published reports of an empirical 72 percent "learning curve", meaning that current unit cost drops by 28 percent with every doubling of output. Figure 9 demonstrates that in terms of the price per bit there is indeed a historical 70% price slope.

Volume manufacturing cost of 256 Mb DRAMs on 200 mm wafers would be nearly \$1600/wafer or a good die cost close of \$15/cm². The average selling price of a 256 Mb DRAM in (early 2001) is estimated to be \$25-\$30 based on extrapolation of current 16 and 64 Mb DRAM price trends, about 10 cents per Mb. Figure 10 demonstrates this point.

For EPROMs the learning curve is of 79 per cent type, i.e. doubling output of EPROMs reduces average cost by 21 per cent.

An important characteristic of semiconductors is the strong and regular price fall, both for the price of a single chip and for the price per bit (binary information unit). For a *given* technology, the cost per chip is falling over time as a result of improved yield. After learning, there is no further scope for cost reduction through improvements in the yield factor. To decrease cost further the number of chips per wafer must increase, i.e. a new technology with a smaller design rule must be adopted.

The price patterns for DRAMs appear to follow the typical life cycle. At the beginning of the product cycle of a given generation, the price is very high, but it quickly falls to a level where it becomes competitive with a previous generation in terms of per bit price. The unit prices are initially very high, then decline - rapidly at first and then less rapidly - to reach a low range (typically after 7 years) and finally tend to increase until significant shipments end. This life-cycle pattern also appears to apply to other types of memory chips.

Each chip density and subtype has a typical life-cycle pattern

for prices and quantities. Quantities of shipments of chips of a specific density begin with small numbers, grow to a peak, and then decline to insignificant numbers. Unit prices start at typically high amounts, decline to a low and then increase as the chip nears the end of its lifespan. The lows for unit prices may coincide with peak shipment rates, or they may lag several years. Table 1 illustrates this pattern for 16-kilobit DRAMs.

The primary determinant of memory chip prices is density. By and large, the larger capacity, higher density memory chips will sell for more than lower density chips. For selected chip types, the life-cycle price patterns for different chip densities result, over time, in chips with increasingly higher densities offering the lowest price per bit of storage capacity. This pattern starts with 4-kilobit DRAM chips in 1975 and ends with 16-megabit chips in 1995. In 1995, the cheapest price is less than 0.2 percent of the cheapest price in 1975. See figures 11 and 12.

Historically DRAM prices have followed the "pi-rule": for each generation of chips prices tended to decline asymptotically toward the \$3 level ($\pi = 3.14$) as mass production of that generation peaked and to half that level at the end of its life.

On the other hand a bi-rule (meaning doubling) is also observable, suggesting that in the future every new-generation chip will approximately double in price as mass production peaks. An example of the bi-rule is the appearance in the mid-1980s of VRAM technology chips, i.e. special video memory chips, which led to persistent price premiums for VRAMs. The prices of VRAM chip have been roughly double the prices of standard technology DRAM chips of the same density. Figures 13 and 14 illustrate these patterns.

The price index for memory chips declined at a 37-percent average annual rate from 1975 to 1985 and at a 20-percent average annual rate from 1985 to 1996.

The price index for microprocessors declined at a 35-percent average annual rate from 1985 to 1996.

In February 2000, ASPs of all semiconductors (integrated and discrete combined) had fallen to \$6.31 after peaking at just over \$9 during November 1999. In April 2000, over the previous twelve months, average sales prices (ASP) had plunged by 9.4%. The average microprocessor sold in February 2000 cost \$78.11, 15.3% less than during February 1999 when they peaked at \$92.21 per unit.

The memory market is characterized by the frequent introduction of more advanced versions or generations which tend to replace existing products. The first producer to market a superior product often enjoys favorable pricing for a certain period. As other producers enter the market and production efficiencies are achieved, however, prices are driven down and the product in question changes in character from a high value-added product to a commodity-type product. Price then becomes a primary factor in purchasing decisions.

In the semiconductor industry firms qua time profile of market shares follow one of three distinct strategies in respect to their timing of entry into each new generation of products:

- (1) the leader enters early and the market share begins from unity and falls monotonically;
- (2) the follower follows the leader after some lapse of time and his market share first falls and then rises;
- (3) the latecomer enters late with a monotonically rising share profile.

Intel is known for its a "cream-skimming" rather than forward pricing strategy, introducing a product early but at high price and withdrawing it after other firms begin marketing at lower prices.

Texas Instruments (TI) is a highly efficient producer and known for its marketing strategy of undercutting competitors' prices to capture a greater market share.

Advanced Micro Devices (AMD) is known as a second source producer or imitator which entered late into a given generation and tried to stay until the end.

Table 2 shows the top ten chip makers in terms of 1999 sales and tabel 3 mentions the top ten equipment manufacturers. It is obvious that no company is on the verge of challenging Intel for the number one ranking. The remainder of the top ten company rankings is forecast to display some volatility.

Industry concentration and its related anti-competitive implications are mitigated by international competition. Although the semiconductor industry appears fairly concentrated in the USA, it is relatively unconcentrated worldwide. In 1996 the top leading firms in the USA had a market share of 68%, while the top four companies comprised approximately 35% of worldwide IC sales. The top eight comprised about 56% of total sales

In general, the Hirschman-Herfindahl concentration index appeared to decline from an initially high level, then to nearly 0.1 and at the end of the cycle it rises sharply as

producers drop the product line. The U-shaped time profile reaches the minimum after about 5 years. Figure 15 shows the historical pattern of concentration in DRAM supply.

4. *Significance of Recessions.*

The semiconductor industry seems to go through a recession every four years: in 1977, 1981, 1985, 1990-1991, 1995-1996. The last major downturn was in 1996 after which chip makers raised production capacity too high. It lasted into 1998. The current boom has started in mid-1999.

A typical measure of the business cycle is the book-to-bill (B/B) ratio. The B/B ratio compares new chip orders to prior sales. In April 1996 the ratio had dropped to 0.78, its lowest point since 1985. This meant that for every \$100 worth of chips the industry was making, shipping and billing, it was only taking orders (bookings) for \$78 worth. In April 2000 the ratio was 1.45.

The B/B ratio is a three month moving average of seasonally adjusted bookings and billings computed from the WSTS (World Semiconductor Trade Statistics) out of a voluntary sample of 70 participating firms, representing at least 40% of sales to the Americas.

The predicament of the B/B as an indicator of market well-being is that a monthly value of the B/B may increase versus the previous month in two opposite situations.

- * When orders increase faster than sales, this is a positive situation indicating that business is growing.

- * When orders decrease more slowly than do sales, this may happen when the market is in a slump.

The same situation applies to a decrease in the B/B ratio, which may decrease when orders decline faster than sales, which is interpreted negatively. The B/B ratio also may decline because the increase in orders does not keep up with the increase in shipments when the market is booming, e.g. due to lack of capacity.

Although the B/B has usually portrayed market conditions accurately, it may mislead its users by announcing a false change in market direction in very critical times.

Two situations may illustrate this.

- * In the third quarter of 1983, the B/B decreased for a couple of months after almost a year of steady increases. This was a false alarm, since neither sales nor orders followed it.

- * In the first quarter of 1985, the B/B indicated that the market was improving. Sales data disproved it. The B/B went

from 0.61 to 0.75 because sales were decreasing faster than orders. Thus, the ratio of orders to sales improved, while the market itself was heading down.

The Semiconductor Industry Association (SIA) decided to cease publishing the IC B/B ratio three years ago, although the semiconductor equipment industry association continues to do so. In this sector the B/B cannot serve as market predictors either. Two almost identical periods of B/B decline had opposite results. The B/B decline at the beginning of 1995 was followed by a strong 1995 market. And the B/B decline at the beginning of 1996 was an overture to the 1996 recession. Therefore, a steep decline of the B/B does not guarantee a recession, nor does a steep increase assure that a strong growth will follow.

These cases have provided enough evidence to discount the B/B as an accurate predictor of turning points. Using the B/B to predict the future is nothing better than guessing. Bookings deliver better predictive information than the B/B and they actually call the turning points in shipments.

With each cyclical downturn, semiconductor companies have been forced to make painful adjustments. US firms reacted by laying off workers and cutting back on new capital investment. In Japan due to lifetime employment practices firms were precluded from lay-offs of large segments of the workforce. Deep financial pockets enabled them to invest heavily in new plant facilities in particular during recessions. The large vertically integrated structure of Japanese firms utilized the built-in advantages of cross-subsidization out of profits earned by the sale of downstream consumer electronics products which placed them in a better position to deal with recessions.

Due to a slump in semiconductor sales in 1974-75, US firms reduced dramatically their capital investment in new production facilities. When demand for semiconductors began to increase in 1977-78, shortages of production capacity rapidly emerged. Facing lengthy delivery delays, many US customers turned to Japanese firms as a source of supply.

The principal lesson for US merchant semiconductor producers was the need to avoid a shortage of fabrication capacity after a recession. Therefore, by investing in new production capacity during the recession US firms expected to recapture in 64K and 256K DRAMS the market share they had lost in 16K devices. The same lesson has been learned e.g. by Samsung,

which despite Korea's crisis continued to invest through the downturn and thus enjoyed fat profits in 1999 when the market surged again.

5. Global Competition.

The DRAM market has become the battlefield for the product development of commodity chips. This market has seen a dramatic change in its structure starting at the end of the 1970s. Figure 16 illustrates the reversal in competitiveness between the dominant global players since 1980. Next table shows how for the different DRAM devices the maximum market shares have developed between the USA and Japan.

Device type	Volume production	USA	Japan
1K	1971	95	5
4K	1974	83	17
16K	1977	59	41
64K	1979	29	71
256K	1982	8	92
1M	1985	4	96
4M	1990	2	98
16M	1997	n.a.	n.a.
64M	1999	n.a.	n.a.
256M	2000	n.a.	n.a.

At this moment the 16Mbit density is being replaced by the 64Mbit density, while the 128Mbit begins to ship in volume causing the 64Mbit density to peak near the end of 2000.

The US firms have dominated the market since its inception at the beginning of 1970, in particular through INTEL, the inventor of the DRAM. Intel had the leadership in product innovation for the first three generations.

In the early 1970s the US enjoyed a 70% share in the world market, which was less than \$5 billion.

Once large Japanese companies had acquired the necessary process technology and production experience, they entered into DRAM production and invested heavily in capacity. In the late 1970s the US was losing its lead and were overtaken by

Japanese firms in 1986.

Because of the intensity of price competition most of the US firms (including INTEL) abandoned the DRAM production. Until 1994 the DRAM market has been dominated by Japanese companies. In 1980, Japan accounted for about 30% of the memory market. By 1989 they accounted for more than 80%. Thus, during this period, the US moved from being the dominant producer in both memory and more sophisticated chips to being dominant only in the latter.

The rapid emergence of the Japanese industry as a world-class competitor was a planned result of a concerted policy effort of the Japanese government employing a variety of policy tools. The Japanese government principally through MITI pursued three sets of policies.

- * Controlled access, i.e. controlling the links between the Japanese market and international markets by limiting foreign competition in the domestic market through a closure of domestic markets to imports, reinforcing "buy Japan" policies, acquiring foreign technology and know-how in the form of patents, licenses and expertise, and initiating barriers to foreign direct investment.

- * Manipulating the domestic firms to stimulate expansion by R&D subsidies, special depreciation tax breaks and subsidized loans from public development banks for electronics in general and semiconductors in particular.

- * The government through MITI reduced the cost of the riskiest and least predictable phase of the R&D process through support of a joint research venture, the Very Large Scale Integration (VLSI) project which encouraged the diffusion of the generic technologies with wide application and common product techniques. VLSI devices have up to 100,000 circuit elements on a single chip. The VLSI project of cooperative research was wildly successful, producing more than 1000 patents and played a key role in making Japanese firms leaders in semiconductor manufacturing in the 1980s. A concrete effect of the program was the creation of technical information flows between Japanese equipment and materials suppliers and IC producers. Product development was left entirely to the firms. The subsidies under the VLSI were not especially large, but were conditional on a commitment to commercialize resulting innovations.

Various "intrinsic" learning advantages of Japanese firms have contributed importantly to their new positions as dominant

suppliers in this market. Japanese engineers and production workers have greater attachment to their employers so that with the lower turnover and continuity in workforce learning processes are more effective. Because Japanese chip producers were part of larger systems houses they were getting access to leading-edge products before their foreign competitors. This also has put US and other foreign systems houses at a competitive disadvantage.

Therefore, a classic strategy of infant-industry protection and promotion in Japan created a competitive Japanese industry. Due to dynamic economies of scale import protection became a policy of export promotion.

With the growth of the protected Japanese market and the success of the Japanese challenge began a 15-year struggle by the USA to open the Japanese market and to counteract alleged predatory Japanese dumping practices.

In the USA the captive producers were cautious about initiating any trade dispute with Japan. Not only did IBM have substantial investments in Japan, but as a net purchaser it had little interest in policies that might result in higher prices. It were the merchant firms like Motorola which wanted to diminish Japanese competition and to raise the price of their output.

In the last few years since 1992 the *US* has recovered overall market share and took back the lead in terms of where chips are produced.

6. Causes of the Decline in US Competitiveness.

Much of the loss of market share experienced by US high-technology firms during the 1980s derived not from a shortage of innovative capability, but from notoriously poor production yields, low production quality and fluctuating production capacity.

Throughout the 1960s and 1970s US semiconductor firms maintained a bifurcated manufacturing system with one segment oriented toward innovation and new product development, the other focused on reducing the production costs of existing products.

This organizational separation of technology development and production generated serious problems of "manufacturability". There was a fundamental tension between the drive to reduce costs on existing products and pressures to introduce new

products and production processes. The design of new devices proceeded with insufficient input from production engineers concerning the possibility of achieving high yields on different product technologies.

In response to rising land and labour costs and to associated labour shortages in Silicon Valley, a locational dispersal of routinized assembly activities took place. Routinized high-volume fabrication facilities were located at dispersed low-wage sites outside the major metropolitan areas in the USA, and labour-intensive assembly operations at low-wage locations offshore, while R&D and innovation remained clustered in core locations. Figure 17 illustrates this point. In 1992 in semiconductors, California had the highest share of US employment of 29.4%, followed by Texas (14.7%), New York (10.2%), Arizona (9.7%) and Massachusetts (6.5%).

However, under conditions of rapid technological change, this geographical separation of production and innovation generated serious difficulties in transferring new technologies from the laboratory to the factory floor.

Therefore, the organizational and geographical separation of technology development and production undermined the ability of US firms to codevelop both new products and new production capability.

The Japanese challenge was aimed at the weakest link in the US semiconductor industry, namely, production. Japan's rapid penetration of advanced integrated-circuit product markets was the result of a complex set of factors, including low capital costs, a protected domestic market, and a willingness at times to sell below production cost in order to capture market share, i.e. to engage in dumping.

Underlying much of the success of Japanese firms was a close integration of technology development and production activities. Japanese firms were committed to production as opposed to the tendency in the USA to accord higher priority to product technology. The Japanese commitment to device performance and technological sophistication was balanced by a concern for the manufacturability of products and the development of product and process technologies that allowed for high yields in production.

This involved the use of conservative circuit designs, scaling up from existing technology wherever possible to minimize device failure. The Japanese were further down the learning curve and had fine-tuned the fabrication line to eliminate

many sources of device-failure. The high yields by Japanese firms reflected quality control and investment in production automation.

In contrast, most US producers employed more complex circuit designs encountering serious yield problems.

Close relations between semiconductor firms and equipment suppliers were another characteristic of semiconductor manufacturing in Japan, which facilitated investments in new equipment technologies and supported the emergence of a strong equipment industry, that contributed to the Japanese success in DRAMs.

Relations between US semiconductor firms and equipment suppliers were often strained. Rather than developing long-term partnership agreements with equipment suppliers, US semiconductor firms switched among many competing firms in a search for the most advanced technology. In addition, they transferred much of the cost of fluctuating demand to their equipment suppliers in the form of cancelled or reduced orders for capital equipment. Quick to double orders in boom times, device makers moved even faster to cancel during the bust. This undermined the ability of suppliers to finance the development of next-generation manufacturing technologies.

A final factor helping to secure greater market share for Japanese firms was the large integrated organizational structure of Japanese semiconductor firms (Keiretsu system) which created low cost of capital and placed them in a stronger position for dealing with a recession. They benefited from an internal price discount allowing a rapid moving down the learning curve.

Japanese semiconductor manufacturers recognizing quality as a strategic weapon adopted Statistical Process Control (SPC), Total Quality Management (TQM) and Total Preventive Maintenance (TPM) into their semiconductor operations in order to reduce process variance and defects and to improve the reliability of their semiconductor equipment.

7. Recovery of US competitiveness.

The reasons why the US semiconductor industry succeeded in recovering from the loss of competitiveness can be carried back to factors at the firm level, at the policy level and industry level.

In response to the competition from Japan, from the mid-1980s onward, the majority of US semiconductor firms initiated a major restructuring of their manufacturing operations in order

to increase yields and improve production quality. Much of the attention of US semiconductor firms is now focused not in the research laboratory but on the factory floor; the ability to stabilize new technologies in production and then to ramp up rapidly to high-yield production is central to the process of continuous innovation. Increased emphasis is placed on the simultaneous development of new technologies and improved production processes.

Manufacturing systems were reintegrated and recentralized around a core of ongoing innovation along Japanese lines. This "Japanization" involved much closer cooperative ties among customers, producers and equipment suppliers and the creation of multidimensional product teams on the basis of "flexible lean production". Locational decisions were driven no longer by factor input costs but rather by issues of communication and learning. A shortage of fabrication capacity has been avoided by heavily investing during recessions.

These actions have substantially improved manufacturing performance in the USA. While the yields of Japanese semiconductor firms remain somewhat higher than those of their US competitors, the gap has substantially narrowed. Product defects in the US declined from an average of 170-190 parts-per-million in 1986 to an average of 50-60 parts-per-million in 1990. Probe yields of US firms increased from 60% in 1986 to 84% in 1991. During the same period, yields achieved by Japanese firms increased from 75% to 93%, thus narrowing the difference in yields from 15% in 1986 to 9% in 1991. This reduction in the yield differential enhanced the ability of US firms to compete with Japanese producers during the late 1980s.

8. Semiconductor Trade Agreements and their Evaluation.

At the policy level the conclusion of bilateral trade agreements with Japan is a second factor contributing to the recovery of competitiveness.

In the USA the industry recession of 1981, when the Japanese companies attacked the international market for the first time, created demands by US semiconductor producers for trade relief. Steeply falling prices for semiconductors along with the early Japanese capture of 70% of the US market for 64K DRAMs triggered a political response by the US industry.

However, the regular trips by representatives of the Semiconductor Industry Association (SIA) to Washington got a

cool reception there.

- * The Reagan administration had a rhetorical commitment to free trade and confronting US producers with a rude shock of foreign competition and a healthy dose of competition was no cause for alarm.

- * The US semiconductor industry was hardly on its deathbed: the merchant industry was still profitable.

In 1985 the market situation changed dramatically as the electronics industry throughout the world entered a deep recession that lasted until the middle of 1987. In an effort to maintain sales volume, both US and Japanese producers cut prices which for 64 DRAMs fell from \$4.00 in 1984 to \$1.00 in 1985.

The industry recession in 1985 was extremely severe and concentrated on the memory chip market. It pushed virtually every US producer out of the DRAM market. Only TI and Micron remained in the merchant DRAM market, although IBM and AT&T continued captive production. Imports were not a direct cause of the industry recession: Japanese penetration actually fell in the two years after 1984.

In 1985 the famous cross-over occurred. The trending down of the American market share and the going up of Japan's has been called the X-curve. By the end of the decade, Japanese firms held in excess of 70% of the world market for DRAM integrated circuits.

In 1985 the descent of the semiconductor industry to Washington received a much warmer welcome than in 1982. In 1982, the industry was split on filing an antidumping petition and faced resistance by the Administration on any Section 301 action; in 1985, its course of action has been largely welcomed by the government, having to do with the appreciation of the US dollar and the large trade deficit.

US firms complained about two issues: a lack of access to the Japanese market and dumping by Japanese firms.

- * By the end of the 1970s US threats had already led Japan to eliminate all formal trade barriers on semiconductors, so that equal opportunities had been created. Since this did not lead to a rise in US semiconductor exports US industry shifted to demanding equal outcomes. In order to increase the market share of US firms a Section 301 action of the Trade Act of 1974 against Japan was prepared that should make "the cash registers ring". Actually the relatively small US market share in Japan had to be explained by quality and marketing deficiencies.

The SIA based its demands on the now familiar "market share shuffle", in which Washington cites a low market share in Japan as proof of a rigged economy. This would strongly suggest that market barriers existed in Japan, although no specific impediment to imports could be identified. However, if captive production (that is chips produced by Japanese semiconductor firms for own use) is excluded from the count, American firms already had about a 20% share of the Japanese market in 1985. This was about the same as the Japanese share of the American market at the time.

* US semiconductor firms claimed that Japanese firms should be penalized for their unfair practices of dumping 64K DRAMs at less than fair value, with fair value being defined as the price required to gain a normal rate of return from the production and sale of DRAM devices. Between June and December 1985 a series of antidumping and unfair trade practice suits have been filed in the US, charging Japanese firms with dumping 64K DRAM chips and EPROMs. Even the Department of Commerce, unprecedentedly, initiated own dumping complaints against Japanese firms.

Although prices for these chips in the US market actually have been marginally higher than prevailing prices in the Japanese market, (the exact opposite of the traditional concept of dumping defined as sales abroad at less than home market prices), the US complainant charged that Japanese chips were being sold at prices not covering the full costs of production, the new definition of dumping in the US trade laws.

In June 1986 the ITC found that Japanese firms were selling DRAMs and EPROMs at a weighted average of 20.75% less than fair value and tariffs were recommended on Japanese imports equal to the margin of dumping ranging from 10.9% to 35.3%.

However, in fact this would be an empty victory due to the speed at which this industry evolves. The ruling should come into effect after the industry would have moved on to the next generation (256K). In the USA it takes a full year to process antidumping complaints.

This is too long for domestic US HT industries with their short product cycles where foreign producers may cease dumping one product and move on to selling its next-generation successor by the time an antidumping case has run its course. Then there would be few imports on which to impose the dumping margins. Therefore, fast track dumping procedures would be required to avoid that domestic suppliers are exiting production such as in DRAMs with its delayed antidumping

remedy.

In DRAMs the antidumping provisions would be applied late and would encourage anticompetitive cooperation and collusion among Japanese suppliers, while in EPROMs they would be applied early enough to deter dumping and to encourage competition.

An alternative to antidumping duties could have been a countervailing US subsidy to offset the injury to US DRAM producers. But this was a nonstarter given the ideological and budgetary climate prevailing in the US in 1986.

Another problem with the dumping charges was that the definition by the US Department of Commerce of "fair value" as average cost plus an 8% markup for normal profit did not take into consideration the existence of learning economies. It did not admit a role for "forward pricing". Forward pricing means that prices are set to yield a profit when total revenues and costs are summed up over the entire product cycle. Forward pricing is normal in a learning industry, i.e. selling at a price below current static marginal and average cost. Below fair market pricing by the Japanese was simply an indication of learning, whereby American authorities reached an incorrect conclusion. When fixed investments in R&D are very large in relation to a firm's sales, such as in the semiconductor industry which spends almost 15% of sales on R&D, there is a significant gap between short-run average cost and long-run average cost, and long-run marginal cost may fall significantly below short-run marginal cost. In this case rational firms engage in forward pricing, that is choose output levels where marginal revenue lies below their current short-run marginal cost, while marginal revenue equal terminal (not current) marginal cost. Figure 18 illustrates these points.

While the ITC found that many Japanese companies were selling their semiconductors in the US at prices below their calculated production costs, there was little evidence that this was done to undercut the prices of US producers. Instead, it was more the result of intensive competition within Japan and of a drop in demand for personal computers in the mid-1980s, which caused the prices for chips to fall rapidly. In order to cut their losses, many Japanese semiconductor firms which had overproduced and had bulging inventories sought to cut their losses by quickly selling off their stockpiles. In this case low prices have been confused with predatory pricing while Japanese firms legitimately tried to capture the economies of learning by doing. Therefore, in the case of

learning by doing pricing below marginal cost is normal business practice that should not be condemned as dumping or predation. Dumping should be assessed on basis of actual price differences between markets and not on basis of constructed cost measures, at least not in the way the ITC did it.

Although the Electronic Industry Association of Japan (EIAJ) and the SIA kept the international trade lawyers busy by filing counterbriefs to each other's briefs, in the end the pressures to move forward with a significant market-opening initiative against Japan triumphed. In order to short-cut subsequent legal actions Japan moved to reach a bilateral settlement with the USA.

Besides an exchange rate policy aimed at reducing the foreign exchange value of the dollar, the US Administration formulated a two-pronged policy:

- * Market-opening initiatives aimed at diverting protectionist pressures by focusing on measures to open up the Japanese market rather than closing the US market. This led to the conclusion of the Semiconductor Trade Agreement (SCTA) with Japan in 1986, which has been renewed in 1991 and 1996. With the signing of the SCTA on September 2, 1986 the actual imposition of antidumping tariff penalties was avoided and the dumping cases involving 256K DRAM chips and EPROMs were suspended.

- * The provision of multi-year financing for a consortium of US semiconductor firms created in 1987 to develop new process technology: SEMATECH.

8.1. Contents of the SCTA.

The 1986 SCTA contained eight provisions equally divided between a price-fixing part and a market-sharing component.

- 1) The SCTA established an explicit price floor for semiconductors intended to promote competition by halting predatory dumping practices: this amounted to a voluntary export restraint (VER) by Japan. Japan would provide the US with cost information necessary to calculate price floors for DRAMs and agreed not to sell products at prices below these values.

- 2) The SCTA contained provisions aimed at doubling the US market share in Japan by 1991 to counter the alleged market closure: this amounted to a voluntary import expansion by Japan (VIE).

A secret side-letter to the Agreement called for increasing the foreign share to 20 percent by 1992. This secrecy allowed

both sides to maintain their public commitment to the principles of free trade and to deny that they had carved up markets in a managed trade agreement. However, the effect was asymmetric: Japan denied there was any explicit commitment about guaranteeing a market share, while the US held Japan accountable for such a commitment though it could not produce the text in public to support its position. US negotiators interpreted the accord as a guarantee that Japan would increase its consumption of US semiconductors to the 20% level, while Japanese negotiators interpreted the figure as a goal that might or might not be met, depending on the demand for US semiconductors in Japan. Therefore, there was a fundamental misunderstanding about what was involved. Japan regarded the 20 percent figure as a target at which to aim, while the US considered it a firm commitment - and a minimum one - which the Japanese had promised to fulfill.

8.2. Subsequent events.

There were almost immediately problems. While the artificial controls drove up chip prices sharply in the US, the market distortions created an arbitrageur's dream. Some of the arbitrageurs (more commonly known as smugglers) took advantage of the bargain basement prices in Japan, where the average chip cost at least \$2 less than elsewhere, and flew hither and yon with satchels and suitcases stuffed with semiconductors. One bag of smuggled chips might save a savvy buyer from the US or Europe tens of thousands of dollars.

To implement the Agreement MITI established a production cartel issuing quarterly forecasts of chip demand and production. It should be recalled that in Japan no specific impediments to imports could be identified so that Tokyo had no effective means of rectifying the situation. Amazingly, the cartel was greeted by screams from the SIA that MITI was trying to create "artificial shortages". In February 1987, MITI began issuing "requests" for production cutbacks which were met by the following month.

The regulation of Japanese export sales implied the adoption of an export licensing system in combination with certificates of Japanese origin. MITI had to register foreign purchases of Japanese chips and established informal regional allocation guidelines to prevent diversion of exports from one export market to another.

Initially, prices remained low and the US warned Japan that it was not adhering to the Agreement. In 1987 US firms accused Japan of violating the agreement by

selling DRAMs at below fair value in third markets (primarily Taiwan and other Southeast Asian countries). Then Oki Electric was lured into documenting sales at less than fair market value in Hong Kong. In the spring of 1987 the USA responded by imposing punitive duties on \$300 million of Japanese exports to the USA on power tools, computers, and TV sets to the US. Tariffs were deliberately not set on semiconductors themselves because they were essential to many American user businesses.

The retaliation had two apparent effects.

- 1) The US share of the Japanese market began to rise;
- 2) The prices of chips began to rise and Japanese chips cost American computer manufacturers 30% to 40% more than before the SCTA. Personal computer prices shot up drastically in the late 1980s, almost destroying America's competitiveness in this high-tech product area.

The US government reversed course and asked MITI to abandon the price production controls and in November 1987 it partially removed the spring tariff sanctions.

From 1987 through 1988 in DRAMs the overall price pattern was one of significant regional price differentials in contract pricing between the domestic Japanese and overseas markets, which, however, disappeared in 1989 due to a slackening of demand. This may suggest that government price and export controls in Japan were relatively effective in controlling direct transactions between Japanese producers and their customers. However, this did not apply for the secondary spot market where arbitrage equalized prices. Figure 19 illustrates this situation.

Even after MITI ended its guidance and the chip market began to weaken in 1989, Japanese producers implemented cutbacks in DRAM production to boost prices and they made excessive profits on global sales of \$4 billion between 1987-91, which were ploughed back in R&D further improving Japan's competitive position. R&D expenditures in chips in Japan exceeded those in the US by \$2 billion in 1988.

Coincident with the implementation period of the SCTA there was increased activity by US firms to penetrate the Japanese market. This was accompanied by a plethora of tie-ups and joint activities between Japanese and US firms. It is difficult to say how many of these were due to the SCTA and how many would have occurred anyway in response to business conditions. In our opinion they were very important for US semiconductor firms to regain competitiveness.

When the agreement was signed in 1986 US semiconductor firms had a market share in Japan of 8.6%, which increased to 14.3% by the third quarter of 1991, so that by that time only half of the desired 12% increase in US market share has been achieved. As the market access target of 20% had not been met in the summer of 1991, the USA and Japan entered a new round of negotiations on semiconductor trade.

In August 1991 a second five-year agreement was signed between the USA and Japan, which endorsed the existing target of a 20% market share for USA producers by the end of 1992.

The agreement abandoned the flawed VER policy of price floors because American using computer firms were hurt by the price floor. However, Japanese firms were still required to collect production cost information to be provided to the US government on occasion of future dumping charges.

Although the US market share in the fourth quarter of 1992 reached 20.2% (while in the first three quarters of 1993 it fell to 18.1%) this cannot be called a temporary success because it resulted from a modest rise of American exports to Japan and a contraction in the total market for chips in Japan. In other words, the numerator rose slightly while the denominator fell strongly.

Although the VER part had been abandoned, in reality if Japan would produce too much or export at too low a price, it would be subjected to immediate US dumping complaints.

With the price floors removed, the price of DRAMS fell substantially during 1991-92, driven down in large part by emergent *South Korean* producers. History almost repeated itself.

In April 1992 Micron Technologies filed an antidumping petition against three Korean manufacturers (Goldstar, Hyundai and Samsung). The higher duties would force one large US computer manufacturer, AST Research, to move 700 production jobs overseas. In exchange for US suspension of the antidumping case, Korea was in favor of embracing a managed-trade agreement modelled after the 1986-1991 SCTA with Japan. However, an agreement was never signed because of opposition by Micron Technology which in April 1992 had filed an antidumping petition against South Korea. It felt secure behind high antidumping duties imposed against Korea and was unaffected by the prospective Korean market-opening actions. In October 1992, the Commerce Department announced dumping margins as high as 87% against Samsung, Goldstar and Hyundai. However, in May 1993 the Commerce Department revised its preliminary antidumping fines drastically downward so that Micron was deprived of its anticipated protection.

8.3. *Renewal of the SCTA in 1996.*

Until mid July 1996 the achievements of the SCTA were limited according to the Americans. The 20% target represented a relatively modest market share. Even though this immediate goal has been met, there was little evidence of a structural change in trading relations. Therefore, additional aggressive intervention, ("cautious activism") by the US government had to be pursued.

In contrast to the Bush administration, which tried to win trade concessions by demanding reciprocity, the Clinton administration is using the principle of comparable access with market share as the yardstick by which the efficacy of its trading partners' market opening efforts are measured.

The US government officials issued statements supporting renewal of the SCTA. The Clinton Administration believed that the success of America's semiconductor industry was the result of the SCTA. However, it is not. The US semiconductor industry is successful today because it sought joint ventures with Japanese firms which gave American firms access to the Japanese market.

It was hard to picture a US industry less in need of government assistance. The US semiconductor industry was made up of companies with strong earnings and a bright future, not companies that were in need of assistance from the federal government in the form of an affirmative action program to help them sell products to Japan.

Given the last decade's massive changes, US producers would seem to have little to complain about regarding access to Japan or, indeed, any other country in the world. With high prices and record profits, the American companies would seem to have nothing to complain about. This should remove the entire *raison d'être* for the renewal of the semiconductor agreement. The best rationale supporters of a renewal offered was that an extension was somehow necessary to preserve and consolidate past gains by the US industry, what had been dubbed the "chicken soup" argument (as in: it could not hurt).

The US position with respect to Japan suggested a fixing of the actual 30% level as the floor and measuring ongoing "progress" to infinitely as a way to expand its foreign market share in Japan.

However, in 1996, the SIA ignored its earlier assertion, made in 1990, that the 20% market share contained in the SCTA was a threshold after which market forces should be permitted to

take over and operate. With the foreign market share at nearly 30%, the SIA wanted even more, arguing that its market share should be much higher.

In 1996, the Japanese market was fully open; the foreign market share in Japan for semiconductors had more than tripled over the past ten years from 9% in 1986 to more than 30%.

Since then the market for semiconductors had become global. There had been a dramatic growth in international business partnerships and a tremendous expansion of the Asian semiconductor industry. Japanese firms worked side by side with their foreign partners in all aspects of semiconductor development, production and marketing. Therefore, a multilateral approach would be essential, as a bilateral agreement could no longer adequately address the evolving requirements of a dynamic, rapidly changing global industry. The Japanese government did propose the formation of a "Global Governmental Forum on the Semiconductor Industry", with the US, Japan and the European Union as founding members.

On August 2, 1996, a new Semiconductor Trade Agreement has been concluded consolidating the situation at that time with two separate accords:

- * a government-to-government pact that turns most responsibilities over to the industries of the two countries setting up the Global Governmental Forum (GGF) and,
- * an industry-to-industry agreement that outlines steps to be taken and establishes a similar industry forum, the Semiconductor Council, that will consider broad semiconductor policy issues.

Under the new agreement, industries will collect a variety of data, including foreign market share, and report their findings to governments.

Governments will review the semiconductor market structure using both qualitative and quantitative factors to ensure the maintenance of open and competitive markets without discrimination based on capital affiliation.

While the new agreement preserves a bilateral aspect, it provides for the participation of other semiconductor producers in a new multilateral forum. Countries or trading blocs such as the European Union would be invited to join the global groups provided they eliminate semiconductor tariffs.

8.4. Evaluation of the SCTA.

Given the innovative nature of the SCTA and the obvious interest in applying this approach to other sectoral disputes, a careful evaluation is warranted.

Firstly, considerable dispute arose over the extent to which price floors were to be applied to sales in third-country markets. The SCTA was the first bilateral deal to explicitly involve monitoring of third-party markets.

The USA announced sanctions against third-country dumping applied to Japan. In reaction, the Japanese government through MITI kept pressure ("provided guidance") on firms to hold production and investment in new capacity down and this brought third-country prices up to US levels.

Secondly, a point overlooked by the Americans was that Japanese suppliers choose to cooperate rather than compete. Since the 1986 SCTA, Japanese DRAM manufacturers moved from competing for market share to market sharing. Japanese chip producers were collectively cutting back production to achieve high price stabilization allowing bubble profits. In contrast, in the EPROM market, where non-Japanese suppliers held 40% of the market, there was no effective cooperation among the Japanese suppliers.

Although there is no direct evidence to examine the credibility of allegations of this collusive behavior in DRAMs, fact is that in early 1988 spot prices for DRAMs in the US soared to historically unprecedented levels and the US computer industry was plunged into crisis; producers scrambled for supplies of critical memory chips.

Thirdly, in the SCTA's antidumping provisions the Japanese agreed to increase their prices, in return of which the USA dropped their dumping charges. By the time prices began to rise in the USA all of the major US manufacturers had already withdrawn from DRAM production.

However, the American computer industry strongly opposed the antidumping provisions because it had been harmed by the sharp runup in DRAM prices. The price floor amounted to an annual tax of \$500-600 million on US computer buyers. The boosting of DRAM prices created windfall profits for Japanese chip manufacturers which made them more productive. Therefore, in DRAMs the SCTA's antidumping provisions actually made matters worse by creating a price floor policy which made the US a high-cost production location. The SCTA has put downstream users of semiconductors at a competitive disadvantage and encouraged computer firms to move production abroad.

Fourthly, the SCTA's greatest benefit of the USA in the long

run may be that it encouraged substantial foreign direct investment (FDI) by Japanese firms in the USA. During the mid-1980s, all of the major Japanese semiconductor firms opened fabrication facilities in the USA, primarily for the production of DRAM devices.

Fifthly, the access provisions for penetrating the Japanese market are very controversial. The 1986-SCTA was a departure in US trade policy. It sought to expand access for American chip exports to a foreign high-technology product market, rather than to reduce foreign access to the US market. It became the first US example of a VIE measure.

Although VIEs were designed to increase trade and competition in countries in which structural impediments limit access for foreign suppliers, they are to be criticized because they result in the cartelization of markets; they increase prices by limiting competition; they are subject to capture by producer interests in the importing or exporting country; they increase the risks of retaliation if the targets are not met; they can create dangerous precedents that could come back to haunt the demandeur and they violate the principle of non-discrimination.

Moreover, VIE import targets are arbitrary on several dimensions. The particular commodities that come under the scope of a VIE are arbitrary. The broader the industrial aggregate chosen for an import target, the more arbitrary the VIE becomes by including different types of goods.

US competitors are not necessarily competitive in all product segments and not all those segments may be appropriate to the needs of the foreign market.

No satisfactory methodology can calculate the target market share; its choice therefore is inherently arbitrary and devoid of any serious economic foundation.

Furthermore, there is the question of what criteria are used in picking and choosing the industries to benefit from US government action. The arbitrary nature of selecting industries for VIEs raises the possibility that political pressure results in the wrong sectors chosen for a VIE.

There is an inherent uncertainty surrounding the import target. The problem is whether failure to satisfy the import target is evidence of Japanese recalcitrance, or is the target set at the wrong level, or has the composition of demand in the Japanese market changed? Any shortfall is ground for complaint by the USA and any increase is hailed by Japan as progress.

VIEs may not increase competition but merely create rents for the first few foreign (US) firms that are beneficiaries of the action, especially if they are imperfectly competitive and recognize their bargaining power vis-à-vis their Japanese customers and if they already have long-standing direct investments in Japan with selling advantages over other US rivals.

The VIE may be a facilitating practice that fosters collusion, just like VERs. The act of the Japanese government forcing Japanese firms to reduce their domestic sales and to share the market with foreign rivals has given rise to a more coordinated and more collusive interplay between foreign and Japanese firms. In the end, competition may not have been enhanced, only profits will be shared.

VIEs are likely to become managed trade in the worst sense. They require substantial government intervention to become effective, depending on explicit and continual administrative or enforcement actions. Imports must be rationed and allocated among domestic consumers to satisfy the market share target. Such results-based trade policy is not about opening markets at all; it is about granting special favors to prominent and politically powerful US industries. To be credible, the VIE must be backed by the implicit or explicit threat of retaliation in case of noncompliance.

VIEs may degenerate into discriminatory and preferential treatment for certain suppliers, leading to trade diversion, constituting export protectionism for US producers. The Japanese government and firms interpret the VIE as encouraging imports principally from the USA. Japan recognized that the pressure to import more arose almost exclusively from the USA. VIEs make a country believe that it can achieve market opening without reciprocal liberalization, reducing support for the open multilateral system. VIEs are inherently bilateral and damage third countries. As the setting of import targets by two countries is perceived by other countries as fixing market shares to their detriment, bilateral trade restrictions tend to spread. Other countries interpreted the VIE as a preference to US firms. Hence, the EU has pressed for an own market share target of 5% in Japan. Its market share in Japan was only 1%, while its share outside Europe and Japan was 5%. Therefore, VIEs tends to carve up world markets by political fiat and pressure. Smaller and weaker countries with less political and economic influence are left behind to fight over the remaining scraps of the market. This threatens the WTO system.

Finally, blaming unfair discrimination abroad or unfair practices for one's own economic shortcomings is an easy way to avoiding serious discussion of domestic solutions. The intense obsession and focus on Japan's hidden practices reinforced the faulty notion that Japan could be blamed for the economic shortcomings of the USA.

If the USA wants to reduce its current account deficit, reduction of the fiscal deficit and the promotion of domestic savings are a vastly superior approach to VIEs.

It may be expected that once its own house is in order, the political pressures for the management of international trade will subside.

Finally, it should be emphasized that for importing countries VIEs and VERs have negative welfare consequences, which may be measured in terms of the familiar changes in consumer and producer surplus and which also encompass unfavorable terms of trade effects.

9. Strategic alliances.

Today the US semiconductor industry is more competitive and prosperous than it was before the SCTA. Now it is the world's largest producer of semiconductors.

Since the 1986-SCTA the nature of competition in the semiconductor industry has clearly altered as is indicated by the proliferation of joint ventures between the US and Japanese firms. The manifold joint ventures have diminished the high degree of rivalry between US and Japanese firms.

America's renewed success in Japan has occurred because of private sector initiatives by US and Japanese companies to work together in strategic alliances and joint ventures and despite the US government's managed trade policies. In fact American chip manufacturers had lost interest in gaining a 20 percent share in Japan even before the semiconductor talks in 1986 opened. Due to the enormous amount of money being poured into research and development, more and more Japanese and US chip makers were putting aside their past rivalry and forming cooperative alliances. Figure 20 illustrates the situation already existing in 1990.

The key technological and manufacturing reasoning underlying the formation of interfirm partnerships has been the shift to Very Large Scale Integration (VLSI) production and submicron fabrication. This shift has led to a rapid increase in the costs of R&D, equipment, and facilities, as well as to an increase in the risk of market failure. Mass volume sales

constitute the sine qua non of low-cost production and of moving rapidly down steep learning curves. Therefore, it is essential to find ways of getting close to foreign customers. Because the up-front costs and risks of breaking into foreign markets can be prohibitively high, there are strong incentives for companies to find foreign partners through strategic alliances. Companies cannot afford to confine themselves to domestic markets, no matter how large they may be.

Not all alliances have to last forever to be considered successful. Constantly changing market forces make long-lived alliance a thing of the past. Successful alliances need dedicated resources. An alliance is not a way to divest yourself of applying resources to something; it is a way of leveraging those resources toward accomplishing a goal. Alliances should be established from a position of strength, not from a defensive posture to stave off a threat to business. Many alliances crumble under the weight of any of a number of factors: poor management, a lack of clear goals at the outset, the growing dominance of one partner and the drain on resources by another, and the failure to adequately measure a partnership's performance. With the change for failure so high, the sheer number of alliances being formed is a wonder. In industry at large, the average company that had no alliances a decade ago has more than 30 today, according to Andersen Consulting.

Alliances remain so popular because of the allure of flexibility, informality, speed and efficiency. As technology becomes more complex, costly and speculative and as customers demand more integrated tools, semiconductor equipment and materials companies appear to be pursuing alliances in record numbers. Alliances with competitors are a newer strategy in the equipment and materials sector than in the integrated device manufacturer side of the equation.

The vast majority of US-Japan alliances is between small- or medium-sized US companies, (many of them young start-ups) and large, vertically integrated, diversified Japanese corporations, the *kaisha*. Small venture start-up firms in the US in need of funds, manufacturing foundries and marketing outlets, look to large deep-pocketed vertically integrated and diversified Japanese corporations to meet these needs. Many of the large Japanese giants look to small US start-ups to provide new product designs to fill niche markets or to compensate for certain deficiencies in their own innovative capabilities.

Partnership agreements between US design houses and foreign

wafer fabrication foundries represent a substantial proportion of the total number of strategic alliances established during the 1980s.

Interestingly, one of the driving forces behind the US-Japan strategic alliances is the need for large Japanese corporations outside electronics to diversify. In Japan established steel and equipment companies are making the transition into the high-tech world of semiconductors and electronics. Perhaps the most obvious reason for this diversification is the Japanese practice of lifetime employment. When the core business loses comparative advantage, the "kaisha" begin branching out into promising new fields of business activity.

Diversification enables them to retain their work force, utilize sunk investments and survive as corporate entities.

However, the spread of alliances raises concerns as well. The prevailing flow of semiconductor technology through alliances is from the US to Japan. At present the USA is trading product design technology for Japanese process and manufacturing technology. A largely one-sided outflow of technology from the US to Japan, if continued over the 1990s, could have the cumulative effect of eroding the foundations of America's capacity to innovate in the industry, with serious consequences for the US computer and telecommunications companies that use semiconductors. Therefore, as US design technology leadership is the cornerstone of US competitive advantage, this may be a risky game.

It is ironic that Japanese and American businesses have sought ways to co-exist and cooperate in high technology, despite the ups and downs in Japan-US political relations. If relationships of this sort prosper, then at least one Japanese-American trade sore may have healed itself.

However, 1999 saw the beginning of increased trade tensions between the USA and the EU. Time and time again, the US arm-in-arm with the EU have pressed their international allies to liberalize trade and to open up their markets. A case in point for the semiconductor and equipment industry was the commitment to convince more than 40 countries in 1996 to sign the Information Technology Agreement. That agreement eliminated tariffs on nearly all information technology products by 2000, including semiconductors and capital equipment, covering more than 95 percent of world IT trade.

As the semiconductor industry has globalized, most US

manufacturers of semiconductor equipment and materials have grown increasingly export-dependent. As a consequence, the majority of large US exporters in the semiconductor industry have formed Foreign Sales Corporations (FSC) which allow them to exempt a portion of their export sales or lease revenues from direct income taxes if those revenues were generated by offshore subsidiaries. The number of FSCs has grown across the US economy to include more than 5000 US companies and cover up \$200 billion in trade. This tax provision was established by Congress in 1984 to ensure that US exporters, who are subject to a system of direct taxation wherever their income is generated, are not at a disadvantage relative to European exporters that operate under a territorial tax system that does not tax foreign-source income.

The EU protested its practice on the grounds that it constitutes an export subsidy, which is prohibited under Article XVI:4 of the WTO rules. In September 1999, the WTO ruled that FSCs are indeed actually an illegal export subsidy and had to be dismantled by October 1, 2000. However, the US government filed an appeal of the WTO panel's decision, with hearings held in late January. On 24 February 2000, the Appellate Body upheld the Panel's finding, to the disappointment of the US, that the FSC measure constituted a prohibited export subsidy.

10. Research Consortia and their Evaluation.

The semiconductor industry has pioneered in large-scale R&D consortia. During the 1980s governments in the US, Japan and Europe launched a myriad of cooperative R&D programs by providing subsidies to firms enabling them to share the risks and costs associated with technology generation.

In Japan the government through the state-owned telecommunications firm Nippon Telegraph and Telephone Corporation (NTT) in 1976 established the VLSI project and in the US in 1987 SEMATECH has been launched.

The VLSI MITI-supported joint research effort in Japan was organized around five companies and accounted for almost 40% of Japan's national IC R&D effort in the late 1970s. The VLSI project was conceived of as a catch-up program designed to bring Japanese producers up to the standard of competence of Western companies. It was not intended to produce major breakthroughs in the fundamental technologies of the IC. However, it extended and improved on technological concepts already developed overseas.

By 1979 due to the objections raised by US industry and government to the large scale of the subsidy for VLSI projects the joint research lab was shut down. However, the Japanese industry continued a private sector edition of the VLSI project for another seven years, funded entirely out of its own monies. Immediately after the VLSI joint lab was disbanded two similar collaborative R&D labs were established as part of new government-industry R&D initiatives. Joint research labs have since become a familiar element of technology policy in Japan.

It may be concluded that the VLSI effort was an exceedingly important boost to Japanese semiconductor technology.

SEMATECH has played an important role in the revitalization of the US chip industry. Although its role remains controversial, the creation of SEMATECH, while focusing on the creation of process technology, coincided with the resurgence of US chip industry.

The establishment of SEMATECH in 1987 represented a major joint response of policy and industry to the decline in the US semiconductor industry's performance. SEMATECH, located in Austin, Texas, provides an example of the use of joint development consortia among the American leading companies in partnership with the US government to strengthen competitiveness. It was granted antitrust immunity. Its goal was to bring US semiconductor manufacturing capability to equal or exceed the world's best, including the design for manufacture as much as the manufacturing process itself.

SEMATECH was not intended to manufacture any particular product, or to develop specific processes for any product. It is a non-profit organization, originally consisting of 11 US companies, that is not permitted to sell chips. The original mission of SEMATECH was to provide a research facility for member firms to collaborate on projects to improve their semiconductor manufacturing process technology.

The benefit to corporations which contribute to SEMATECH occurs from having access to newer equipment and processes six to nine months before they are generally available, which may be crucial for leading-edge product introductions.

A main problem was that, although the development of advanced manufacturing processes is crucial to the competitive advantage of firms, member firms are reluctant to share such sensitive information with other members.

Moreover, there was the danger that some firms could free ride on the contributions of the technology leaders. Therefore, members questioned whether the development of advanced manufacturing processes was an appropriate objective for an industry consortium.

In response to these controversies, SEMATECH altered its research agenda to one that sought to improve the technological capabilities of US SMEs and to strengthen vertical cooperation between US suppliers and users of semiconductor process equipment. Within two years of operation, the focus of the consortium changed from the on-line testing and optimization of existing manufacturing equipment to strengthening the SME industry. Three firms have withdrawn from the consortium: Micron Technology, LSI Logic and Harris Semiconductor, because of their dissatisfaction with the consortium's decision not to pursue the development of an advanced manufacturing process that all members could apply.

US affiliates of foreign firms were not allowed to enter SEMATECH. SEMATECH was not open to non-US firms, though there has been some discussion with the European JESSI program over mutual research interests. There were no restrictions on joint ventures between SEMATECH members and foreign partners.

In 1994, with US semiconductor manufacturers and equipment suppliers again atop the world market share charts, SEMATECH considered it could fund itself and sought an end to federal matching funding. In 1996 US Congress voted final funds for SEMATECH.

The costly conversion to larger silicon wafers which is altering many of the industry's manufacturing technologies has given rise to new recently established consortia.

Two recent established consortia are the International 300mm Initiative (I300I) in the US, established in November 1995 comprising 13 leading device makers and Semiconductor Leading Edge Technologies (SELETE) in Japan established in February 1996 by ten leading Japanese semiconductor firms. The aim of these consortia was to upgrade the wafers from the standard 200mm to 300mm which should increase the yield in the number of chips per wafer 2.6 times.

Unlike the VLSI project and SEMATECH, both I300I and SELETE have been financed solely by member companies, including semiconductor manufacturers from around the world. The

development costs of 300mm tools require a radical overhaul of equipment tool sets and are likely to exceed \$10 billion, far higher than the \$1 billion cost of developing the 200mm tools in the early 1980s. These consortia focus on vertical projects aimed at ensuring the reliability and compatibility of production tools.

Moreover, the costs of individually leading these transitions and "going it alone" to 300mm wafers outweigh the benefits of having first mover access to the new capabilities. For the first time leading international device makers developed a uniform set of standards in advance of a major wafer transition in order to avoid incompatible equipment. Historically equipment suppliers have looked to device makers for technical guidance in setting these standards and device makers tried to speed tool development and reduce the costs of obtaining a compatible tool set for next-generation fabs.

I300I is an international subsidiary of SEMATECH and is housed in the SEMATECH facility in Austin, Texas. To reduce the danger that proprietary information will leak among competing suppliers I300I has adopted a decentralized approach in which most equipment projects take place at the facilities of individual supplier firms instead of the consortium's common facility. I300I evaluates tools for basic test parameters and leaves the development and subsequent improvement of those tools to suppliers. In contrast to SEMATECH which obtained 89 patents between 1989 and 1996, I300I did not expect to own any intellectual property.

SELETE aims at both the evaluation and development of 300mm tools and has an annual budget more than twice that of I300I. In contrast to I300I SELETE is more centralized so that equipment is evaluated in SELETE's central laboratory at Hitachi. The risk of technology leakage among supplier firms is greater than in the case of I300I. SELETE also generates jointly owned intellectual property.

Both consortia are pursuing an open policy of evaluating tools from suppliers worldwide. E.g., in 1997 Canon shipped a 300mm lithography system for testing to I300I.

Recently the transition to 300mm wafers has been delayed due to a combination of technical and economic factors. Faster-than-expected reductions in the line widths of circuit patterns have permitted more chips to fit onto each 200mm wafer which extended the life of 200mm fabs and equipment. Moreover, the Asian financial crisis has constrained the

capital expenditures of Asian companies. As a consequence, high-volume 300mm production is not expected until 2002. This sudden change in market outlook for 300mm technologies illustrates an insufficiently appreciated risk of industry-wide collaboration in a fundamental uncertain environment. Therefore, industry-wide collaboration may increase the collective exposure of firms to unexpected developments.

The I300I program represented for the first time that leading semiconductor firms from seven countries can agree to conduct joint projects. This relatively high level of international cooperation among competing manufacturers is without parallel in the history.

I300I demonstrates that the role of government in this industry is diminishing.

With the cessation of Federal funding of SEMATECH in 1996, SEMATECH began reducing its operating budget and initiated plans for including non-US firms in a set of international projects. In April 1998, SEMATECH expanded its global participation and launched International SEMATECH with 15 participating companies, 2 from Asia, 3 from Europe and the 10 US SEMATECH members, however, without Japanese semiconductor firms as members. From that time on I300I is a division of International SEMATECH. It will phase out its tool evaluation activities and will select tools for joint development or improvement projects. In 1998 for the first time SEMATECH exchanged information with the Japanese consortium SELETE in order to develop international standards.

In Japan, SELETE coincides with a new wave of government-funded semiconductor R&D initiatives. Due to the competitive crisis in the Japanese semiconductor industry in 1996 a new MITI supported consortium, the Association of Super-advanced Electronic Technologies (ASET), located at SELETE's central facility, was launched to advance the technological frontier at the design-intensive end of the market. It represents a new era of private-public collaboration in Japan.

It may be concluded that the formation of SELETE and ASET is analogous to the establishment of SEMATECH. Periods of collective crisis have resulted in collective action that involved industry-wide coordination and periodically government-industry action. The new initiatives I300I and SELETE have been devised and funded by private firms and government influence was only indirect. However, even in the face of unprecedented cooperation between firms in different countries, the transition to a new

technology may be impeded by unforeseen events. This illustrates an important risk associated with the collective priority-setting and technological forecasting of industry-wide consortia.

10.1. Evaluation of SEMATECH.

Although SEMATECH remains controversial, many credit it with saving US industry's place in semiconductor manufacturing. It is difficult to separate the influence of SEMATECH from other changes taking place in the industry and hence to argue what would have happened without it or what would have happened had federal sponsorship taken other forms. Although the improvement in performance of the US semiconductor manufacturers may be attributable to SEMATECH, there is little credible direct evidence that SEMATECH is responsible for such gains.

One of the most significant effects of SEMATECH is the impact on the purchasing habits of US semiconductor manufacturers, who have increased the amount of equipment they buy from US suppliers, due to the increased reliability of equipment under SEMATECH programs.

It may be objected that SEMATECH was transformed from a research joint venture into a bailout for US semiconductor equipment manufacturers. The discoveries made never proved profitable because demand from US chip producers for the equipment remained weak. One company, Silicon Valley Group Lithography (SVGL) even formed a ten-year technology-development partnership with one of its major Japanese competitors. In this sense SEMATECH's support for SVGL is a way for American taxpayers to subsidize a rival semiconductor equipment maker in Japan.

It has been said (Dick, 1995) that the combination of unrealized goals, shifting priorities and costly bailouts has made SEMATECH a resounding disappointment. The consortium had not at all changed the total R&D spending of its members. SEMATECH did not raise member firms' returns on assets, did not raise firms' investment-to-sales or investment-to-assets ratios, and did not have any appreciable effect on industry productivity. Own internal company R&D spending was more productive than investments in SEMATECH. The costs of SEMATECH transcended the government subsidies paid for by taxpayers. In 1992 it has been remarked that SEMATECH had spent five years and \$1 billion but there were still no measurable benefits to the industry.

There are several reasons why SEMATECH failed to be successful.

First, SEMATECH was devoid of entrepreneurial spirit. It favored older, more established companies over innovative start-ups. Many successful small chip manufacturers refused to join SEMATECH. Put bluntly, consortia like SEMATECH were formed by people who have lost.

Secondly, the decision not to produce commercial chips deprived SEMATECH of crucial manufacturing experience through learning by doing. One cannot go down the learning curve without manufacturing.

SEMATECH imposed considerable cost for society.

First, SEMATECH refused to allow non-US firms to join its ranks and blocked joint ventures between members and Japanese partners. It denied American firms the scientific and manufacturing advances of foreign competitors.

Secondly, it undermined the longstanding US opposition to large-scale technology development subsidies of other countries and it eroded the US authority to oppose and to persuade trading partners to abandon such subsidies.

Although the US government *supported* funding for technology development activities within the SEMATECH consortium, it *opposed* technology and product development subsidies extended by European governments to the Airbus consortium. Therefore, SEMATECH has undermined US legitimacy in opposing foreign governments' industrial policies and has encouraged the US semiconductor industry to become insular and protective.

11. The Position of Europe.

11.1. European weakness.

The semiconductor sector is the most evident area of European weakness.

Throughout the 1970s European systems companies grew increasingly dependent on chips produced by US companies.

However, this posed no threat to the European companies because the intense competition among US merchant semiconductor manufacturers meant a continuous stream of new leading-edge products with prices dropping rapidly.

Today Europe must also reckon with Japan (and Asia more generally). Europe has fallen into third place in the global electronics competition, suffering dependence on not just one but two competitive regions.

European producers in 1991 held only 10% of world semiconductor production, compared to 38% for the US and 46%

for Japan.

The European producers hold less than 40% of their own market. More than 30% of European use is supplied by foreign companies manufacturing in Europe. The rest is provided by imports. The trade deficit in active components was \$4 billion in 1990 and in 1997 in high-technology products the EU had a trade deficit of \$25 billion, as shown in figure 21.

Europe did not have an entrenched position in any segment of the sector. In DRAMs only Siemens remained in the game. Moreover, the equipment that underlies production is dominated by Japan and the US.

The positions shifted in favor of Japan in the 1980s and have shifted back toward the US in the last several years.

One area of European semiconductor strength is in application-specific and customized chips that are adapted to particular market needs and usually made with processes that are not state of the art.

Part of the European problem certainly lies within European companies, i.e. their limited ability to bring new products to the market, but part also lies in the character of the fragmented European market which eliminated the potential for European specialization. Another reason for European weakness has to do with the national champion policies of European governments.

Firstly, European firms held back from early adopting cutting-edge technology. This reflected a low level of demand from the European computer industry as well as a reluctance to move away from existing profit centers. E.g., Philips' success with the germanium alloy junction transistor, the diffused transistor and the Gunn diode, made the firm conservative and slow in adopting silicon as a semiconductor material.

Secondly, the fragmentation of the European market into a set of national submarkets did not allow European firms to produce on a scale comparable to US or Japanese firms. The creation of the Single Market benefited American and Japanese firms more than European ones. They captured the benefits of economies of scale. The American and Japanese have established extensive production facilities in Europe in anticipation of restrictions that would close the market to them. Through foreign direct investment American companies preempted the developing European market for advanced products that European companies could not yet supply.

Thirdly, the "national champion" policies of European

governments disregarded the fundamentals of competition. European governments had a static view of building competitive strength: large size would ensure success and therefore governments focused on creating large national champions. But by so doing they removed many competitive pressures so that the resulting firms remained relatively weak.

Adherence to a dynamic view might have led to a greater focus on developing new products rather than creating large firms. The European governments did not promote cutting-edge research or innovation and did not contribute to the creation of new products. With the exception of Germany's second Electronic Data Processing (EDP) plan in 1971-1975, basic research was downplayed in Europe.

European firms took much of their technology from US and eventually Japanese firms in the form of licensing and resale agreements. Where new technology had been created the greatest weakness in Europe was the inability to successfully commercialize it. Technology is only a necessary condition for success in the IT industry. Commercialization is as important as technology innovation.

The main difference between the US and European industries was that troubled firms in the US left the industry, while those in Europe were merged together and subsidized, leaving the resulting firm weak.

European policy has made things worse because support has gone to those activities that encouraged European firms to compete directly with American and Japanese firms in the main industry segment, rather than identifying and entering new niche markets.

Overall, the European producers did not appear cost-competitive, were generally slower and less effective at establishing new product niches and spent less on R&D than their Japanese competitors.

At the moment, the points of leverage and advantage in new product lines are dominated by the Americans and the Japanese. The Americans create distinct product definitions, which are often produced for them by the Japanese. The Japanese often produce next-generation design improvements, which the Americans often then distribute under their own labels. There is seemingly little room for European companies unless they are able to find new and innovative product strategies which have to be commercialized successfully.

11.2. Forms of Protection in Europe.

The European Commission recognized the strategic role of semiconductor industry as a key component supplier for the computer, telecommunication and automotive industries. European production is considered important for having alternative supply sources and to alleviate the risk of dependence on foreign suppliers.

In the early 1980s no urgent sense of crisis seemed to mark European trade policy. Formal barriers to semiconductor imports were relaxed a bit.

For semiconductors there was a common external tariff of 14% until 1 January 1998. For downstream products such as computers and telecommunication equipment tariffs are applied from 4.5% to 7.5%.

In the 1980s *tariff suspensions* played a significant role in IC imports. European chip producers began asking for tariff suspensions, which for a given period, permitted non-payment of all or some of the duties applicable to imported goods. Goods imported under the suspension arrangement enjoyed freedom of movement throughout the Union. It allowed enterprises to obtain supplies hardly available in the EU at a lower cost for a certain period, so that it became possible to stimulate economic activity, to improve the competitive capacity and to enable a reduction of consumer prices and to create employment. The use of tariff suspensions became so widespread as to effectively open the European market, reducing the average collected duty to 5 percent of import value which has been a significant (though not overwhelming) factor in lowering prices in the European market. Some 20 percent of IC imports benefited from duty suspensions.

Repeated use has been made of *antidumping actions*, which have been initiated by the European Electronic Components Association (EECA). The investigations concerned DRAMs from Japan (1987-1990) and South Korea (1991-1992) and EPROMs from Japan (1986-1991). The investigations ended with positive findings so that exporters were accused of high dumping margins. The proceedings were concluded with price undertakings in which exporters accepted minimum export prices, while companies not participating were confronted with definitive antidumping duties. The intention of the price floor was to provide a "safety net" for European producers, to encourage them to increase their investments in an environment free of fear that prices would fall below production costs as a consequence of cutthroat Japanese competition. A target of 20 percent of the European market for European-based firms has been mentioned as the desired outcome of the safety net. To

avoid the negative welfare implications of price floors in which foreign exporters collect implicitly the duty through the price undertakings and in order to balance the interests of producers and users the European Commission set the floor prices at a relatively low level.

The European price floors differ from the American Fair Market Value (FMV) system. The European reference pricing scheme includes a profit margin of 9.5 percent added on full cost, compared with a 8 percent minimum profit margin used in US-constructed cost calculations.

The American system is more stringent in that it attempts to eliminate soft dumping (selling at prices below one's own cost, but not necessarily below the cost of more efficient producers), while the European system is more liberal in that it bans only hard dumping (selling at prices below even the most efficient producer's full average cost of production). A defender of the American system might reply that it is more liberal because it permits efficient producers to expand at the expense of less-efficient producers, while the European scheme hinders even the most efficient exporting firm by setting a price above its cost.

This entire discussion is moot. More important is that an era is beginning in which different regions of the world are setting floor prices for key semiconductors using inconsistent and incompatible pricing formulas.

Antidumping measures against Japan were not particularly effective in improving the competitiveness of European producers and in halting the erosion of their world market share in DRAMs, which fell from 13% in 1993 to 11% in 1994. Moreover, minimum prices were effectively binding for only a short period of time during which the market was in recession. As soon as the DRAM market recovered by the end of 1992, prices picked up. Antidumping measures against Japan have not helped to improve the position of EU producers in DRAMS, although it has spurred increased FDI for DRAM wafer plants. The large gainers in the DRAM market during the last years are the South Korean companies with Samsung as the leading producer.

In the case of EPROMs, European producers have been more successful, although it is difficult to judge whether this is due to trade policy. Since 1993, SGS-Thomson has become the market leader in EPROMs due to its outward orientation. However, EPROMs will become obsolete and become entirely substituted by flash memories, a market which is dominated by Intel and where SGS-Thomson is still a marginal player.

In February 1989, the European Commission approved a regulation that drastically altered the *rules of origin* for chips made in the EU. Although a small change, it had very large consequences for the origin assigned to chips produced and consumed in Europe.

Before 1989, the origin of a chip was assigned to the country in which the last substantial process or operation that is economically justified was performed. In practice the location of assembly and testing was the *de facto* standard for origin. Under the new rule, origin is determined by the place of fabrication, or diffusion as it has been called, (this is the process by which electronic circuit elements are etched on the wafer). For a semiconductor to be qualified as a EU product and to be exempted as a screwdriver plant to avoid antidumping duties, the wafer diffusion process must be carried out in the EU. This had triggered off a wave of foreign direct investment in the EU since 1990.

The major loser was Japan. About 40 percent of Japanese companies' sales in Europe qualified for national origin based on the old rules, while under the new diffusion standard only 12 percent of sales qualifies for national origin. American producers gained by the change because their share in European IC sales qualifying for national origin roughly doubled to 50 percent.

Interestingly, US chip producers, not the Japanese, reacted most negatively to the change in the rules of origin. Part of the answer is that the gains were very unevenly distributed. The big loser was AMD which did test and assembly in Europe but had not invested in costly fabrication lines. In fact some European subsidiaries of US companies had lobbied in favour of the change in regulation. Another reason is that the determination of origin internationally virtually took place on the basis of the testing and assembly standard, so that the change in Europe seemed to be an open assault on the prevailing mainstream consensus.

The example given by the Americans of the losses suffered was the case of a Japanese printer company, being found guilty of dumping in the EU, that had opted not to use US chips on its printed circuit boards because of the new rules of origin. Japanese producers were faced with the requirement to use non-Japanese components, not European components. According to the "anti-screwdriver" regulation (designed to prevent circumvention of a dumping penalty through the minimal performance of local assembly of imported parts) a 40 percent minimum level of non-dumped content was required to avoid dumping penalties.

The problem remains how to decide the nationality of assembled printed circuit boards for electronic products on which semiconductors have been mounted and in which many parts from many different countries have been assembled.

It may be concluded that the way protection has been granted to the semiconductor industry has made the EU a high cost location for the user industries, slowing down the diffusion of innovative products and production processes. Protection in Europe has not helped to reduce significantly import penetration in semiconductors, nor has it increased the ability to export. Therefore, it was not in the public interest to rely on trade policy actions which tended to raise the cost to the user industries.

11.3. Unsuccessful European Strategy.

It is interesting to compare the European strategy with the Japanese one. The European strategy was clearly unsuccessful. Firstly, Japan restricted FDI and used import substitution to create and promote indigenous suppliers. The US could only benefit from market growth in Japan through licensing and transfer of technology.

The European strategy was one of import substitution through substituting the local production for imports from America. In essence Europe's policy consisted of trading, i.e. discouraging imports for FDI by American companies without technology being transferred to Europe.

Secondly, the objective of the Japanese strategy was the creation of a Japanese industry, whereas the European objective was the establishment of a European production base, regardless of ownership.

The Japanese strategy closed the Japanese market to investment by American companies, reserving domestic demand for Japanese companies and forcing US firms to transfer technology to Japanese competitors if they wanted to profit from growth in that market.

Thirdly, Europe's difficulties in semiconductors were aggravated by the failure of a promotional policy in the computer industry. The basic European computer strategy was to protect national markets with tariff walls and to select "national champion" firms that were given favored treatment with direct subsidies and preferential procurement.

This strategy was a failure, the reasons of which include:

- * Being sheltered from competition often meant lessened pressure to stay technologically abreast in a rapidly changing market.

- * Being pushed by national policy to go head-to-head against IBM in existing markets and applications (rather than identifying and entering new markets) has proved unsuccessful in the computer industry.
- * Alliances to gain access to new technology with US producers often left European partners stranded with an installed base of an orphaned technology.

The weakness of the European computer industry implied that there was a relatively small demand in Europe for the high-performance state-of-the-art chips that were driving technology development in the USA.

European chip production focused on discrete semiconductors and ICs oriented toward the telecommunications market. European chip-manufacturers placed the emphasis on servicing the needs of local equipment manufacturers rather than competing with foreign producers in the more rapidly developing global markets tied to the computer industry.

The attempts to protect the European semiconductor and computer industries from imports have created a vicious circle.

- * High tariffs and high costs for imported semiconductors meant higher prices and diminished sales for European computer systems makers.
- * Diminished computer sales meant a smaller demand for locally produced semiconductors and this meant greater political pressure for protection, and so on.

The Europeans continued to target the computer industry directly with relatively little support for the semiconductor industry, while the Japanese promoted the semiconductor industry directly as a means of building strength in the computer industry.

The solution chosen in Europe was to protect the chip market and to permit free investment within Europe by foreign producers in order to maintain access to leading-edge semiconductor technology developed abroad. Only in the late 1980s Europe finally began to develop programs to support the semiconductor producers.

11.4. European Management of Dependence.

If in a globalized interdependent world economy technology would flow rapidly across national and regional boundaries, there might be no need for European electronics policies. However, there is no guarantee that relevant technologies will be available in a timely fashion within Europe. Therefore, it

would be best to have evolving technology close to home to profit from any spillovers, so that local technological capabilities need to be nurtured within Europe.

Until the end of the 1980s the European semiconductor producers have not found distinctive solutions that would allow them to capture powerful competitive positions that could be translated into standards and proprietary technologies that could be the base of competitive advantage. Europe's dilemma was that American and Japanese firms, not indigenous European producers were the primary source of advanced electronics technology.

In the short term the fear was that Europe could not hope to re-create under European control the various elements of a sophisticated electronics supply base. Therefore, assuring leading-edge technology was a matter of securing access to other regions' supply.

Europe had to ensure that European producers have market access to the supply bases of the US and Japan.

Diversity of supply would be essential to guard against exploitative dependence; several suppliers in at least two regions ought to be the policy goal. Europe had to settle for maintaining alternative regional sources, maintaining a healthy US-Japan competition by playing suppliers in the different regions off one another.

The question for Europe was how it should manage this dependence.

Should Europe accept free imports of semiconductors to maintain lower prices, focusing on users and emphasizing applications know-how, while downplaying concerns about foreign supplies of technology?

Or should Europe restrain imports to encourage local producers, even if that involved penalties for the users employing the products, emphasizing the need for intimate access to rapidly evolving cutting-edge technology?

In the past, European policies for the diffusion and use of advanced technology never received the same attention and weight as did producer-oriented support. The policy debate emphasized the production of particular products, not the broad economic gains from widespread adoption of new technologies benefiting users (computer makers). Not the users but the producers received the most policy attention.

It was very difficult to establish the appropriate policy balance between emphasizing user application by adopting new foreign technologies by allowing imports of components and

promoting directly the development of particular products. Now, it is recognized that these two views are complements. A strong application position can create a foundation for strength in the production of underlying components. A dialogue between technology projects and user companies is required. Integrating users and producers of technology right at the start of R&D processes facilitates production and diffusion of technology.

Strength in semiconductors often reflects itself in the final product markets. Strong final market position in fact creates semiconductor strength. Final market strengths should be the basis for formulating a strategy to induce innovation in supplier industries.

Highly competitive electronic systems industries require a strong semiconductor industry and a strong semiconductor industry needs strong process equipment and material industries.

11.5. Technology Policy in Europe.

Only in the late 1980s Europe finally began to develop programs to support the semiconductor producers. Since then a growing flow of public subsidies into joint R&D activities in semiconductors has become increasingly central to the European strategy for competing in semiconductors.

The 1983 Megaproject to develop advanced semiconductor technology played a catalytic role in the creation of the Joint European Submicron Silicon Initiative (JESSI) launched in 1989, financed by both the public and private sector. The main purpose of JESSI was to overcome the technological backwardness with respect to the USA and Japan. The result is that Europe has closed many of the technological gaps between its industries and those of the US and Japan, although serious problems remain regarding market share. While Europe has not improved in terms of market share, the downfall spiral has been halted and the European industry is definitely doing significantly better than in 1987 judged by the difference in investments made during the last 2 years.

JESSI's success has been that it has overcome the long-standing reluctance of European companies to work together across national borders on fundamentally important research projects. JESSI has brought Europe's industry back onto the worldstage by combining resources and pooling risks. On December 31, 1996 after an eight-year term JESSI ended and made way for a new European program, Micro Electronics

Development for European Applications (MEDEA), which is stronger on the equipment side and more focused on consumer applications (multimedia, communications and automobiles) than JESSI and in which user involvement is crucial to getting technologies to the market. As a four year program MEDEA will run to the end of the year 2000. Actually it has no budget to fund projects. It is just a coordinating body. To get the support of governments its focus is on applications. MEDEA is focusing on much more finished developments by trying to combine electronic technologies, systems architecture and software technologies. There is, however, a three-year wait between the end of the research stage and the time the first products appear on the market.

One of the most important new areas of semiconductor production in which European companies and research organizations have developed a leadership role, is system-on-a-chip technology, in which complete computing capability is integrated into the silicon circuitry. The competitiveness of the European microelectronics industry relies on the timely availability of complex systems-on-a-chip. This requires the vertical cooperation with material and equipment suppliers as well as with system houses which define the hardware and software.

European firms have engaged in technology exchange and formed strategic alliances in R&D with US and Japanese firms. This may be an effective approach alternative to, or complementary with, independent cooperative development projects.

However, the increasing globalization of the computer industry in the form of a two-way flow of technology between European and foreign firms through acquisitions and alliances may ultimately undermine both the feasibility and necessity of European RTD programs. Globalization makes it harder to help European firms without helping at the same time their foreign partners because technology leaks away to them. At the same time it also enables European firms to utilize technologies from their foreign partners and strengthens the research base of the European firms so that programs such as MEDEA may be less necessary.

12. Evaluation of Strategic Trade Policy.

The case for semiconductors rests on their importance in maintaining a nation's capacity to innovate and commercialize technology. As the semiconductor industry is generating externalities and spillover effects for other sectors it is

considered to be a strategic sector. Therefore, government promotion of strategic industries has become an increasing common practice among nations. This offers strong advantages to first movers due to the rising cost of developing new technology especially if later entry is quite limited. Import protection encourages firms to move further down their learning curve and may act as export promotion.

Each national economy wants a preferably large piece of the same set of high-technology industries that are presumed to be the guarantors of future high-wage jobs, high-value added activities and rising standards of living. By pursuing strategic trade policy, countries want to transfer excessive returns from foreign countries to their own ones. Due to spillover effects the overall welfare of the home country may improve at others countries' expense.

Semiconductors have also been targeted to level the international playing field, to replicate Japanese targeting and to safeguard national defense, especially in the USA. In fact, during the second half of the 1980s, US government support for semiconductor R&D outstripped Japanese government support by a ratio of ten to one. It must be emphasized that Japan's success in the world market is not due to unfair trade and industrial policies. The great Japanese breakthroughs in microelectronics have been driven by entrepreneurial innovation, not industrial policy.

With respect to the defense industry in the US only a handful of specialty companies produce semiconductor chips used for defense applications, so that protecting the entire semiconductor industry is a very roundabout and costly solution to ensure defense supplies. A cheaper alternative is to write long-term procurement contracts with the few firms that focus on the defense market.

Targeting proponents argue that due to spillover effects of research, firms underinvest in research, so that government subsidies are needed to encourage firms to increase their research investment. In fact, however, firms know exactly how to capture the financial return from their research spending, e.g., by forming joint research ventures and by negotiating licensing contracts. On the other hand, the research race involves some duplication of research efforts so that too much investment in R&D also may be a possibility. The problem is to determine the net effect. Moreover, a policy favoring research by US firms will equally benefit Japanese competitors because

technological improvements spill over quickly across borders. Therefore, it is difficult for governments to help domestic firms and not their overseas competitors.

Targeting to preserve jobs may save one job at the expense of another because other industries must purchase higher-priced inputs. In fact, it has been estimated that for each job saved in the semiconductor industry by the SCTA another was lost in computer manufacturing as higher chip prices drove down computer demand. Moreover, many displaced semiconductor workers have ready employment alternatives.

An industry is also deemed strategic if it has the long-term potential to sustain unusually high profits, perhaps because it is difficult for other firms to enter the market and drive down prices. However, actually semiconductor producers have earned a rate of return that is close to the average for all manufacturing industries over the business cycle. This is normal because firms regularly leapfrog over one another to become the new market leader each time that chip technologies change. As there are no large profits to redistribute, the rationale for targeting disappears.

Ultimately, the issue of strategic industries rests on the users of technology rather than producers. Users of the semiconductor technology (producers of computers, telecommunications or consumer electronics) need timely access from producers of chips to the appropriate technology in terms of right quality and functionality at a reasonable cost. Since some set of users will not be guaranteed timely access to the appropriate technology at a reasonable cost, this has been counterbalanced by government policies and industry initiatives aimed at recreating some production capacity within the nation.

The fundamental reason why targeting fails in high-technology industries is that they resist central guidance. Industries such as semiconductors represent industrial democracies that grow from the bottom up by private initiative, not from the top down by government directives.

Although governments always try to pick winners, they often end up supporting the losers. Losers don't deserve support. And winners don't need it. Therefore, the best trade policy is to let consumers buy from winners.

Another great danger of strategic trade policy is that retaliation and protectionism e.g. in the form of a subsidy war may come about.

Finally, there are three considerations which summarize the costs and failures of targeting in semiconductors.

- 1) The charges by US firms on Japanese competitors that they were dumping memory chips during the mid-1980s had as a primary effect that US users and consumers were hurt by forcing them to pay significantly higher prices for computer chips.
- 2) Japan used these profits to fund research toward the next generation of chips leaving US firms even further behind.
- 3) SEMATECH wound up being only a costly bailout of failing US equipment suppliers.

In Europe production of semiconductors (domestic and foreign production) has been the result of the common external tariff on semiconductors which has been eliminated on 1 January 1998. It was not protection for protection's sake, but explicitly to get new production investment irrespective of ownership in Europe behind tariff walls.

In the USA it happened through the semiconductor trade agreements, the creation of SEMATECH, through strategic alliances and through FDI by the Japanese, and in Asia through a variety of concerted government and business relationships. In the USA the government supported the chip industry through R&D contracts and through military procurement especially in *product* technology. In Japan MITI sponsored research in particular in *process* technology.

The aim was to ensure that users of the technology have timely access at a reasonable cost. It is not unthinkable that this type of government intervention is going to continue although its rationale is decreasing.

13. Productivity Paradox in the USA.

According to the hype of the New Economy, information technology has the potential to change the way businesses work and yield a quantum shift in productivity. The reasons advanced include: production planning is made easier; inventories can be reduced; delivery lead-times fall and the nature of distribution is altered. All these factors increase the flexibility of capital goods, making capital investment more attractive and productive than it used to be and encouraging firms to substitute capital for labour. All this should yield soon if not now productivity improvements.

The question is whether the emergence and expansion of the new high-tech industries is making the economy as a whole more productive. Robert Solow stated: "we see the computer age everywhere except in the productivity statistics". To

substantiate this issue R.J. Gordon produced next table, applying for the US economy.

	1950:2- 1972:2	1972:2- 1995:4	1995:4- 1999:1
Non-farm Private Business	2.63	1.13	2.15
Manufacturing	2.56	2.58	4.58
Durables	2.32	3.05	6.77
Computers	-	17.83	41.70
Non-computers	2.23	1.88	1.82
Non-durables	2.96	2.03	2.05
Nonfarm Non-durables	2.68	0.80	1.50

Since 1996 America's non-farm productivity (the benchmark measure) has improved by 2.2% a year up from a 25-year average of 1.1%. In the second half of 1998 non-farm productivity (not in the table) grew by an annual average of 3.4% and during the first three months of 1999 it grew by 3.5%. Not until improvements in productivity growth have survived the next downturn will it be clear that they are permanent ("structural") rather than temporary ("cyclical").

The improvement in measured productivity since the mid-1990 is surprisingly, extraordinarily concentrated in one small sector of the high-tech economy: computer manufacturing. As prices of IT-producing industries declined (by 7.5% in 1997, by 7% in 1996, by 4.9% in 1995, by 2.6% in 1994 and by 2.4% in 1993, contributing to keep inflation in check), productivity growth in computer-manufacturing improved at 42% a year between 1995 and 1999. Although computer manufacturing is just 1.2% of America's output, that improvement was big enough to move the figures for the whole of the private non-farm economy.

If this improvement can be sustained, many (to be exact a recovery of 1.02 points equaling 68% of the 1.50 point slowdown between 1950-72 and 1972-95) claims of the new-economy enthusiasts may be justified. The new economy advocates believe that the benefits in the use of computers (outside of the industries which manufacture computers) has been long delayed but has finally arrived, in spades. The claim is that computers are being used efficiently to create faster growth in the rest of the economy.

However, when looking at the final row of the table the portion of the productivity recovery remaining to be credited to the nonfarm nondurables is less than when durables are included. Thus the recovery from 0.80 to 1.50 is not 68% of the 1.88 (i.e., $2.68 - 0.80$) slowdown over 1950-95 as is the case for the total nonfarm business economy, but a much smaller 37% ($0.70/1.88$).

Examined more closely, the productivity revival, does not provide any evidence of a broad new economy revolution created by the benefits of computers and other electronic equipment spilling over to other sectors of the economy that have invested heavily in them.

What has been less widely recognized is that the admirable performance of productivity growth in manufacturing is entirely located within durables, and within durables entirely in the production of computers. In fact, the change from 2.03 to 2.05 cannot be called a significant acceleration in nondurable manufacturing output per hour.

Therefore, when stripped of computers, the productivity performance of the durable manufacturing sector is abysmal, with no revival at all and a further slowdown in 1995-99 compared to 1970-95. There has been no significant structural acceleration in productivity growth in the 90% of the total nonfarm private business economy located outside of durables manufacturing.

The conclusion is that productivity performance of the manufacturing sector of the US economy since 1995 has been abysmal rather than admirable (Gordon, 1999).

The inventions of the late 19th century and early 20th century were more fundamental creators of productivity than the electronic-internet era of today. Those earlier inventions may be classified into four clusters, starting with electricity (including electric motors, electric light, consumer appliances), internal combustion engines, motor transport, air transport, superhighways, super markets, suburbs), rearranging molecules (petrochemicals, plastics, pharmaceuticals), and communications-/entertainment (telephone, radio, movies, television). These big four were much more profound creators of productivity than anything that has happened recently. Much of what we are seeing now is second order and does not have the fundamental impact of the invention of TV and movies and much of the use of the internet substitutes one form of entertainment for another.

Therefore, the computer technology has proved unbelievably effective at reproducing itself; beyond that its apparent

influence on productivity has so far been somewhere between imperceptible and adverse.

A number of explanations have been put forward for the productivity paradox.

Firstly, computers and information processing equipment are a relatively small share of GDP and of the capital stock. An input with a very small share cannot make a large contribution to economic growth and therefore is not expected to have a major impact on productivity. In 1994 computer equipment (even enlarged to encompass all of information processing equipment, computing software and computer-using labour) accounted for only around 2% or less of the physical capital stock.

Secondly, software prices have declined less rapidly than computer prices. Since real computer demand may be said to be dependent upon the price index of hardware and software, real computer demand growth may be overstated.

Thirdly, in particular sectors like finance and insurance, which are heavy users of information technology, output is poorly measured and therefore, its productivity effects are invisible in the data. To the extent that the weight of services in GDP has steadily increased, overall mismeasurement also has probably increased.

Fourthly, the computer facilitates the reorganization of economic activity along the lines of globalization in the integrated world economy but these gains from reorganization do not show up in economic statistics.

Fifthly, there is a delay of several decades before technological breakthroughs deliver economy-wide productivity gains. Effective use of computers often requires additional organizational adaptations to the use of computers, which may not be instantaneous. It takes time and effort for an organisation to learn how to fully utilise a new technology and realise any productivity growth.

Therefore, there are learning costs relating to adopting a new technology. Because of learning costs associated with the adoption of new technology, its implementation tends to reduce productivity in the short term, even though the potential productivity gain in the long run outweighs this short term loss.

E.g., Compaq Computer Corporation, the world's largest PC manufacturer, estimates that the initial purchase price of a PC represents only about 20% of the total cost of owning and operating that PC in a corporate network environment.

With such substantial learning costs, upgrading technology will usually imply a short run loss and long run gain. A new technology may well seem initially inferior to older methods to those who have extensive experience with those older methods; yet initially inferior technology may well have more potential for improvements and adaptation. This may provide an explanation for the coexistence of high market value and low current profitability in IT intensive companies.

Sixthly, factors that are complementary to computers may be slowly changing so that long periods of time are required to analyze the impact of computer investment. Organizations are complex with a multidimensional performance and their inertia is great for a single innovation to have a substantial impact. Mere spending money on technology does not guarantee a higher efficiency. Computerization does not automatically increase productivity.

Seventh, conventional price indices fail to capture changes in quality and thus understate the growth rate for output and productivity in innovative industries.

Flamm has reinterpreted the Solow productivity paradox as a semiconductor paradox: You see the semiconductor age everywhere and not just in the computer industry. Price indices for semiconductors have dropped more rapidly than computer prices and semiconductors go into other kinds of machinery.

Flamm calculated the consumer surplus from declining semiconductor prices at around 8 percent of annual GDP growth, which cumulates to a huge number over the 50-year history of semiconductors.

Flamm estimated the output growth elasticity of demand for semiconductors at roughly eight times their price elasticity of demand and his percentage point estimate of semiconductor contribution to GDP is around 0.2 for recent years. This number is, fortuitously, similar to the growth accounting calculations for computers!

It must be emphasized, however, that many of these issues around which the productivity paradox revolves are still unresolved.

14. Present Situation and Future Global Prospects.

Global chip sales have increased dramatically during the 1990s. From \$50 billion in 1990, sales jumped to a record \$145 billion in 1999, about three times what they were a decade

ago.

In 1992 for the first time since 1985, US firms captured the largest share of the world-wide semiconductor market when they were responsible for 43.8% of worldwide semiconductor shipments while Japanese firms held a 43.1% market share.

This recovery of US competitiveness derives as much from weaknesses in the Japanese economy as from refound strength in US semiconductor manufacturing.

- * The recession in the automobile and consumer electronics industries is a key factor in the loss of market share by Japanese semiconductor firms. When the recession ends, it is not unthinkable that Japanese firms will regain much of the market share they lost since 1992.

- * Of greater long-term concern to Japan is the loss of market share to South Korean firms which have captured 20% of the global DRAM market, at the expense of Japanese firms, forcing the price of DRAMS to new lows.

- * An indication of the increasing competitiveness of US semiconductor producers is the way they have responded to the most recent period of recession. During the past two years Japanese firms cut back on capital investment, while many US producers added to existing fabrication capacity. This will help ensure large-volume production of the next-generation microprocessors and other design-intensive products introduced in 1993 by US firms.

In December 1995, things started to go wrong.

First, prices started to tumble. The market price of the most common memory chip, which had been as high as \$13 in November 1995, began dropping by more than \$1 a month as PC makers dumped excess stocks after disappointing sales during the Christmas season. By March 1996 the price was down to around \$9.

Second, in April 1996, things got worse. The Semiconductor Industry Association reported that its "book-to-bill" ratio had dropped to 0.78, its lowest point since 1985. That meant that for every \$100-worth of chips the industry was making, shipping and billing, it was only taking orders (bookings) for \$78-worth. Since January 1996 orders were below sales. It was the first time since 1989 that the indicator had gone below 1.0. In February 1996 the ratio was 0.90. This sort of slump sent businessmen to the window ledge to see what was going on there. Manufacturers started to postpone planned expansion. In the first half of 1996, the Philadelphia semiconductor index, a measure of share prices of American chip makers, had dropped 45%.

Both the slump in memory-chip prices and the plunge in the book-to-bill ratio had their roots in changes affecting the PC industry. Those changes stemmed primarily from the rise of software company Microsoft .

In 1995, Microsoft released Windows 95, which needed twice as much memory capacity. As PC users groaned under the hype surrounding the new program, chip makers were slavering at the thought of the extra demand it required. But nothing happened, or not much. Companies were slow to buy Windows 95, partly because of associated hardware costs, partly because it was not clear to them how to use the extra software power, and partly because Microsoft had another more powerful operating system, called Windows NT, in the wings. The result was that many firms decided to wait and see whether to upgrade and did not buy in the meantime.

For users of chips the fall in chip prices was a welcome. However, if memory-chip prices continue to fall, the cash cows used to finance expansion into everything from PCs and cars to aerospace would run dry and the cross-subsidisation from semiconductors would have to stop, which could force firms to pull back from some markets.

Therefore, to say that no one need to worry about falling semiconductor prices, is to underestimate how much a shake-out in the chip industry would matter.

In 1997 world semiconductor sales were \$137.2 billion, the second highest mark in history, representing a 4% increase over 1996 when the total was \$131.97 billion. The moderate growth in 1997 (+4%), was followed by another steep decrease (-8.6%) in 1998.

The world market in 1998 has been valued at \$125.6 billion. The market downturn has been largely affected by the installed overcapacity, particularly in the memory field, adding to pressure on pricing. E.g., the 64Mbit DRAM showed a price erosion of up to 50% during 1998, with an average of 37% at the end of the year.

In 1997/98 and 1999, semiconductor manufacturers and equipment suppliers have experienced sales declines largely due to the Asian financial crisis and excess fab capacity. In 1998 factory utilization rates for total integrated circuits fell to 82 percent.

The downturn created surplus manufacturing capacity that postponed schedules for the transition from 200 mm wafers to 300 mm production facilities. Manufacturing semiconductors on 12 inch (300 mm) silicon wafers instead of the 8-inch (200 mm)

wafers currently used could increase profits substantially since 2.35 times more (dice) chips may be manufactured per wafer. However, the conversion from 200 mm to 300 mm wafers is expected to cost the industry more than \$10 billion in terms of investment expenditure. For 1999-3 the capacity utilization was 91 percent.

In 1999 semiconductor sales were \$145 billion representing a growth rate of 13.5% and they are expected to expand to \$172 billion increasing 17.7% in the year 2000. The market is expected to continue its momentum in 2001 with sales of \$190 billion and ending the year 2002 with \$215 billion of global sales.

The facts that DRAM enjoyed high growth during 1991-95 plus that Windows 95 and Intel's Pentium CPU were released in the market led DRAM manufacturers to the wrong judgment that the DRAM market would keep high growth. In addition, Intel's new venture into motherboard business since 1995 also had a strong stimulus on the DRAM demand side. Many over-optimistic DRAM makers translated the sudden growth of DRAM prices into more investment in constructing DRAM fabs.

However, they neglected one fact that almost all the major players of DRAM industry had already 8" wafer fabs since 1993; in 1996, ten more 8" wafer fabs started operation simultaneously.

From 1996-98, there were totally 26 new 8" wafer fabs in operation, which expanded the DRAM production capacity about 20 times of the original 6" wafer fabs if the capacity of an 8" wafer fab is counted as 1.78 times that of 6" wafer fab. The anticipation of high growth was shattered by Intel's dumping of DRAMs to the market and the problem of over-supply as a result of too many 8" wafer fabs caused an incessant drop in DRAM prices below average variable cost. No DRAM makers were spared the harm and all major DRAM manufacturers were losing money. A reshuffling of players was expected with the result that only a small number of players would stay in DRAM business. This would in turn push up the entry barrier and help to slow down the price drop of DRAM products. 64Mb DRAM was expected to bear the hope of market recovery. As Windows 98 requires 64 Mb DRAM and supply grows only slowly, it was perceived that the DRAM industry would have recovered its prosperity by 2000.

Everywhere you look these days in the semiconductor industry, companies are tearing up their market forecasts and coming up with higher estimates as orders continue to soar. There is no

doubt the global chip industry is running flat out, at virtually full capacity. Worldwide fab utilization was running at 93.6% of capacity in the fourth quarter of 1999. The market that appears to be at risk of overshooting demand is flash memory where suppliers will not catch up with demand.

The main question is whether the soaring chip industry will do it again: expand too fast during the boom times, creating overcapacity which ends up pushing the industry into a downturn? Especially, the pure-play foundries use the current recovery cycle to greatly expand their capital spending. E.g., Taiwan Semiconductor Manufacturing Co.'s capital spending will be 100% of its sales. That is extremely aggressive, even for a fast-growing chip maker.

There are signs that the market for DRAM memory chips could remain slow for 2001 and 2002. Overcapacity is the main concern, as more fabs are coming in line with increased supply.

More concretely, one research house, Advanced Forecasting Inc., (which has a high record of correct forecasting, i.e. has called 90% of the IC industry turning points since 1986) is predicting with an 80% chance a slump in chips and chip-equipment sales sometime in the second quarter of 2000. It is speculated that double and triple bookings of orders from chip makers in November and December 1999 may have led to unattainable expectations. This could cause chip-manufacturers to ramp up (i.e. full-blast) production levels beyond what they actually need and when they can't sell all those chips expectations will fall, dragging down the equipment makers as well.

Today the industry is geographically dispersed. New entrants are flooding in from Asia. And chips are now being used in more industries than before, making suppliers - apparently - less sensitive to any one business. However, these changes have not been enough to flatten out the chip cycle.

Next table provides an overview over the global IC supply in percentages by region since 1990.

	1990	1997	2000
North America	37.5	36.7	35.5
Japan	47.6	35.6	33.8
Europe	10.5	14.9	14.9
Asia Pacific	4.4	12.8	15.8

Source: Taiwan Semiconductor Industry Association, 15 July 1999.

Noticeable is the decrease of the share of Japanese vendors as the Asian Pacific vendors took off, while the share of European and US vendors remained unchanged since 1997.

14.1. European Position.

Despite the severe downturn of the semiconductor world market in 1996 (-8%), the *European* semiconductor market showed a moderate growth of 1.1% in 1998. All other regions experienced a strong decline in 1998 from -9.6% for the US to -19.6% in Japan. The market downturn has been largely effected by the installed overcapacity, particularly in the memory field, adding to pressure on pricing. E.g, the 64Mbit DRAM showed a price erosion of up to 50% during 1998, with an average of 37% at the end of the year.

In 1998, the market share of European semiconductor producers has grown substantially in all the regions so that the three major European players - Philips, SGS-Thomson and Siemens - ranked 8, 9 and 10 respectively. However, the DRAM recovery has reshuffled the top 10 chip ranking.

In 1999 only Philips figured on the top 10 chip makers. European companies tend to put more emphasis upon specialization and customization of circuits than the rest of the world.

The "heavy hitters" Philips, Siemens (as Infineon) and STMicroelectronics, are still very much up at bat, and they are hitting with greater impact. For the most part they have been through make-overs into essentially new semiconductor companies that are more aggressive, more global and more willing to take risks on innovative new technology that has not been proven by circuit manufacturers in other parts of the world. Europe's semiconductor industry is taking advantage of its own large and growing consumer markets, has created a new image for Europe and provides support to European equipment and materials suppliers of all sizes. If Europe can

successfully blend its economies under the banner of the euro currency, it may become the world's largest trading bloc, pushing the US into second place. The revival of depressed Eastern European economies could provide an even larger market for Europe's high-tech products.

Europe's revival is being driven in part by the strong demand for European products for use in consumer products, especially leading-edge telecommunications and automotive electronics. It is now easier to raise money for European companies than at any time in the past. The investment climate for the European semiconductor business has been improved significantly over the last year and has given a push for smaller companies to raise capital through initial public offers (IPOs). Venture capitalists become interested in investing in small companies, which benefit much through close cooperation with research institutes like LETI in France, Fraunhofer Gesellschaft in Germany and IMEC in Belgium.

The general public has recognized that the public retirement system no longer provides adequate financial security, so that they must take responsibility themselves. The public offerings of e.g. Deutsch Telecom made the public aware of the stock markets and the potential for financial gain. The introduction of the Neue Markt in Frankfurt gave the opportunity to invest in affordable small cap companies with their focus on specialized areas of technology.

The niche marketing approach will dominate technology strategies in Europe. Europe cannot compete in the high-volume businesses like DRAMS and microprocessors. Europe has to deliver ICs tailored to the specific requirements of the application. Flexibility and close cooperation with the customer are keys for success. A good example of a growth market is the packaging industry, which is moving toward the front end.

The European semiconductor firms have grown faster than their international competitors and have become more profitable than the average industrial firms. They are leading in the development of next generation technology and have become dominant in several key global applications markets, such as multi-technology projects, system-on-chip methodology and mixed signal/analogue design. R&D and design have transformed into a major European strength. Now Europe has all the ingredients for success.

If Europe is to find its place as a significant player in the

global semiconductor industry this should be based upon a shift from a business model based on economies of scale and industrial might toward a new set of competitive criteria based on intellectual property rather than on capital reserves to invest in own manufacturing resources. Such shifts are already evident in the growth of the fabless semiconductor suppliers and the foundry industry. The development of design methodologies such as the system-on-chip opportunity which can be licensed to multiple chipmakers in soft form allows small IP houses to bring their value-added technology to market without manufacturing investments.

Across the European continent partnerships and alliances between suppliers and customers will become more visible. Since the semiconductor industry will probably always be heavily leveraged toward volume suppliers, alliances and partnerships made possible by a unified Europe actually will create the required "virtual advantages of scale".

The recent development of the European share in percentages in the four regions and worldwide is as follows.

Market	1996	1997	1998
USA	5.8	6.3	6.6
EU	26.3	25.9	28.6
Japan	1.5	1.6	1.8
Asia Pacific	11.7	12.8	13.4
World	10.2	10.8	12.3

Source: EECA, 1999

14.2. Position of Japan.

In 1998, the Japanese semiconductor market faced a strong adverse wind and experienced substantial negative growth. Although high growth had suddenly swung to negative growth in 1996, some positive growth was recovered in 1997. However, this did not lead to full-fledged recovery and 1998 again saw negative growth. In dollars, the market shrunk by 18.1% from the previous year to \$27.92 billion. The falling trend of the last several years could not be stemmed and Japan's share of the worldwide market (in dollars) has fallen from 22.6% in 1997 to 20.1% in 1998. The biggest causes for this downturn were the decline in domestic production of electronic equipment due to the significant economic slowdown in Japan

and Asia and the fall of average unit prices of devices.

A vicious circle exists in Japan, where worsening corporate performance has led to wage cuts and uncertainty about employment. In turn, this has chilled consumption, which further worsens corporate performance. As a result, the demand for electronic equipment has shrunk considerably, seriously dampening the semiconductor market. Nearly all devices have declined from the previous year. All categories of MOS memory, except flash memory, are down considerably.

A favorable cycle, in which income growth leads to increased consumption, cannot be expected soon.

Full-fledged recovery might begin in 2000 and beyond. This projection is based on assumptions that corporate capital investment will increase and income will gradually increase, leading to gradual expansion of consumption. However, growth will be lower than the worldwide growth rates and Japan's share of the worldwide market will continue to decline. This is largely because the electronic equipment market in Japan is saturated, unlike those in other regions. Japan's growth rate will be low because market penetration of electronic equipment is already high, unlike in Asia where many markets have growth potential. Japan's share is projected to fall to 16.2% in 2003.

The Japanese semiconductor manufacturing equipment market also experienced substantial negative growth in 1998, falling by 30.2% on a dollar denominated basis from 1997. This rate of decline is more severe than that of the worldwide market so that Japan's share of the worldwide market continued to fall from 27.7% in 1997 to 24.4% in 1998. The biggest cause for the negative growth was the severe cutback in capital investments made by the semiconductor makers because of the stagnation in the semiconductor market.

With respect to 1999, booking conditions began improving. The B/B ratio has exceeded the threshold of 1.00 since January 1999 for equipment made in Japan.

Although the manufacturing equipment market will wipe out negative growth, this will not likely result in a full-fledged high-growth recovery. Since it takes several months before booking recovery is reflected on sales and many makers are in severe financial difficulties because of the semiconductor recession, there is little possibility that capital investment will grow from the 1998 level, which decreased by 37.1%. The outlook for 2000 depends on capital investment for building manufacturing lines for 300 mm wafers. If this

capital investment occurs full-scale, the manufacturing equipment market definitely will revive. But this will probably not occur earlier than 2001. For now, Japanese semiconductor makers are giving higher priority to the renewal of lines toward circuit dimension reductions than to the introduction of 300 mm lines. They appear less enthusiastic about capital investment for 300 mm lines than makers in the US, Europe and Korea.

More and more Japanese semiconductor firms are rushing to move away from DRAM and emphasizing greater efficiency through moves away from large-scale investments for mass production toward maximum use of existing equipment and extension of equipment lifetimes, a shift from quantity to quality, as it were.

Concluding, the pace of growth for Japan is slower than the markets in other regions, so that Japan's share of the worldwide market will continue to fall year after year, down to 22.8% in 2002 and to 16.2% in 2003. Japan now represents the smallest of the four major markets for semiconductors, trailing North America, Europe and the rest of Asia.

However, the country's economic powers are beginning to get serious about reform. This is witnessed by the NEC-Hitachi DRAM merger, which is remarkable because it marks the first time two non-banking Japanese firms from rival keiretsus have agreed to tie their futures together. Each company will essentially retain ownership of its respective foundries, while the newly formed DRAM company will jointly market and design products that will be manufactured at both existing NEC and Hitachi plants. Each company's products will be sold under the new NEC-Hitachi Memory Inc. name. The intention was to recapture the DRAM championship title from the Korean companies. But in the next one and a half to two years, probably out of necessity, the two will combine forces to invest in 0.13-micron technology, which likely will result in a new manufacturing facility. Apparently consolidations are a natural evolution.

14.3. Position of Taiwan.

In Taiwan in the space of just two decades another kind of Silicon Valley is emerging. Taiwan is a key player in the worldwide semiconductor industry, ranked fourth in the world behind the USA, Japan and South Korea.

In the Hsinchu Science-Based Industry Park mainly Taiwanese home-grown firms which produce computers, IT products and

integrated circuits are becoming significant world players. This high-tech cluster has been created as a deliberate matter of public policy organized and administered by a public-sector agency.

Taiwan's semiconductor industry operates in a vertically integrated structure, which is unique in the world and which covers design, manufacturing, packaging and testing, along with supporting industries such as masks, wafer, chemical materials and lead frame supply. Strong linkage and well-established cooperative relationships among upper and lowerstream companies have made the Taiwan IC industry a highly competitive one. Part of Taiwan's strength lies in the abilities to form joint agreements with companies around the world.

The semiconductor industry in Taiwan has been created and established through a process of *resource leverage* (i.e., the capacity of firms to tap into financial, technological and other resources to accelerate their entry into new product markets or to enhance the capacity to upgrade their process technology) and *sustainability* (potential capability of standing on its own in the face of tough international competition).

In 1973 an institutional framework under the umbrella of the Industrial Technology Research Institute (ITRI) has been established with the conscious intention of facilitating the leveraging of advanced technologies by providing good infrastructure. In 1974 a specialist semiconductor and electronics laboratory was opened in ITRI, the Electronics Research Service Organization (ERSO), which succeeded in signing a technology transfer agreement with the US electronics firm RCA. The ITRI/ERSO was the engine for the rapid *diffusion* of (imported) technological capabilities to the private sector.

Taiwan's semiconductor output is now well-balanced, covering the entire range of ICs as well as contract test and assembly work. This balance allows Taiwan to withstand any downturns and to continue its expansion.

Taiwan's semiconductor industry is a flourishing market-driven strongly export-oriented industry with no nationalized firms. There are no government "handouts" to any of the firms although its creation, its nurturing and its guidance have been entirely the product of government and public sector institutions. The government offers firms which settle in the high-tech cluster attractive terms for setting up a business,

as well as taxation benefits, low-interest loans, R&D matching funds, special exemptions from tariffs and taxes. Firms which are accepted as a resident by that fact alone stand a great chance of raising bank loans for investment.

Its success as a dynamic cluster owes much to a careful provision of infrastructure and social services (schools and medical and health services) as much as to agglomeration effects. There is now even talk in Taiwan of a reverse brain drain from the US back to the island.

In 1983 the entry of Korean firms into the memory chip business forced Taiwan to raise the bar and go all out for VLSI capability. To this end Philips transferred its existing VLSI technology to a joint venture with the new company launched as Taiwan Semiconductor Manufacturing Corporation (TSMC). Its success took Taiwan to the level of technical sophistication and brought Taiwan into the submicron era.

Taiwanese firms that have grown to prominence in the semiconductor industry have avoided capital-intensive and standardized DRAMs and instead focused their efforts on a more diverse range of chips. Many midsize Taiwanese producers have now abandoned DRAMs and are turning their plants into specialty-chip foundries. However, few of them have broken through into own-brand manufacturing. They apply a modified followership in which they align themselves with a technology, but then introduce improvements or innovations of their own. Taiwans' strategies have not acted to constrain their firms' further evolution, but have in fact provided a powerful mechanism for becoming inserted in a rapidly changing world-class high-technology industry.

The Taiwan earthquake on September 21, 1999, which followed the massive power failure in July and which hard hit the Taiwanese semiconductor production, had an impact on the market. It forced spot market prices to treble in a matter of days, and although they fell back quite rapidly, once the full effect was known, the main impact was to accelerate the rate of rise of contract pricing. However, this rise in spot prices did not have a big impact on long-term contract prices between chip makers and PC producers because contracts are negotiated over a prolonged period. When the spot price for DRAM chips was below \$5 during the second quarter of 1999, the contract price was at \$8-9 and when the spot price was up to more than \$15, the actual contract price was still around \$9-13. The overall impact of the earthquake on worldwide annual DRAM capacity was under 1%.

Taiwan provides up to 12% of all DRAM chips globally and a third of non-memory chips. Semiconductor equipment investments are a good indicator of Taiwan's basic intentions in the chip business. From 1992 to 1998 Taiwan has been picking up world market share for equipment at the rate of almost 3 percent a year. As Korean investment faltered, Taiwan surged ahead in the equipment market and in 1997 it held 14 percent of the worldwide equipment market, a position South Korea had occupied in 1995. Figure 22 illustrates this point.

While Taiwan's industry has made manufacturing wonders, innovative products are limited somewhat. In order for Taiwan to have a high-value-added IC industry, it is time for Taiwan's IC vendors to transform their strategy from investing in process technology to innovation-oriented product technology.

14.4. Position of Singapore.

The Singapore semiconductor industry has grown from its beginning as a back-end subcontracting location in the 1960s to a fully integrated semiconductor industry employing cutting-edge technology today. The initial attraction to the area was low-cost manufacturing, but economic and political stability, business-friendly government and a highly skilled workforce have kept foreign capital pouring into the nation. As of the end of 1998 40 semiconductor companies and 160 supporting companies were operating at all levels of the value chain.

In Singapore the strategy of high-technology industry creation has been utilized through leverage from multinational corporations rather than via domestic firms and within a carefully tailored institutional and policy framework. Leverage is a stronger and more active concept than mere transfer of technology and gives content to the notion of spillover effects. The semiconductor cluster in Singapore spans firms in virtually all steps of the value chain, covering the IC design sector, IC (front-end) fabrication, IC test and assembly and ancillary services of equipment and materials. At the heart of the Singapore story lies that more and more start-up firms find their business consisting of *contract supply* of essential components and services to multinationals.

The approach pioneered by Singapore was to offer multinationals favorable conditions for location of their

activities in the host country, with a view to raising overall skill and technological capabilities. In Singapore it has been government agencies like the Economic Development Board, and the National Science and Technology Board that have been the instigators of resource leverage. They have mapped out the strategic architecture of the industrial upgrading programs.

The industry, however, remains overwhelmingly foreign-owned and dependent on MNEs operating in Singapore for technological upgrading and new product development.

The Singapore approach was to utilize the MNEs and encourage them to enter into closer supply relations with local firms upgrading their operations and capabilities. Singapore has turned the practice of leveraging skills and technological knowledge from the MNEs into a high art, pressuring them to broaden the range of their activities.

For all its sophistication, there are some weaknesses that may be remedied as the industry becomes more mature.

In the mid-1990s there were no ICs being produced under the name "Made Singapore", although many ICs are produced there, but under others' brand names and under contract to others. There is not much evidence of indigenous innovation capabilities, nor is there much evidence of a local private sector that can add value independently, although contract and service business is lucrative and in itself technologically challenging.

However, there is evidence of determined industry creation and catch-up efforts mounting in Singapore as well as efforts to reduce initial dependencies which are created by the leverage strategy itself.

Singapore is not just a foreign production site but is becoming an integrated semiconductor industrial cluster. It is now attracting the cream of both US and Japanese semiconductor firms not just to locate their own activities, but to purchase high-quality wafer fabrication services. There is a supportive infrastructure including reliable power, clean water and environmental controls (waste treatment), good training services and human resource support. There are links with other industrial clusters such as advanced chemical and precision engineering firms. Although the output of a spate of indigenous firms cannot yet match that of the multinationals the foundations have been laid and the value-added of the domestic sector continues to expand.

The conclusion is that Singapore's strategy in leveraging its semiconductor industry from MNEs has been amply rewarded in

creating an internationally competitive industry. Although the industry is not yet in a state of sustainability and independence, it is on a clear trajectory towards such a state underpinned by the continuous intervention of state agencies.

The case of Singapore is of enormous interest to developing countries everywhere. In Southeast Asia, Malaysia was one of the first to emulate the Singapore strategy, then Thailand, Indonesia and the Philippines, while China provides an example in the late 1990s.

14.5. The Position of Korea.

In the history of the electronics industry the pace and scale of the capacity and market share expansion of Korea's semiconductor industry is unprecedented. Today the Korean market share of the world wide memory business is about 35% and Korea represents 12% of the worldwide semiconductor materials and equipment market.

The Korean semiconductor industry was focused on mass production of high-technology memory products, primarily DRAMs.

Because the industry cannot meet the current non-memory demand trends in both global and Korean markets, all Korean semiconductor device manufacturers try to diversify their products from DRAM production so that they can be general semiconductor manufacturers as well.

In the early 1990s Korea moved from the position of an insignificant outsider to that of the market leader in DRAMs. Such a catching-up in this industry is a major achievement. External and internal factors contributed to this state of affairs.

Externally:

- 1) Due to the unrealistically high price floors set for DRAM imports into the US through the SCTA of September 1986, Korean producers were able to outprice their Japanese rivals at price levels that generated substantial profits.
- 2) In order to tamper oligopolistic pricing and supply behavior of the Japanese majors, US semiconductor producers and computer companies created an alternative low-source for DRAMs and made a choice in favor of Korean producers.

Internally, firstly, Korea was willing and had the capacity to spend huge amounts of money on investment and technology acquisition. Between 1988 and 1992, Korean semiconductor

chaebol (meaning "financial clique") spent nearly 51% of their semiconductor sales (\$10.2 billion) on capital investment (\$5.7 billion). Moreover, Korean semiconductor producers paid substantial licensing fees for US and Japanese technology. In 1992 and 1993, Korea spent 14% and 16% of its annual turnover on royalty payments.

Secondly, Korean semiconductor companies used specific technology acquisition strategies based on three elements.

- 1) Early on, the chaebol established subsidiaries in Silicon Valley which served as listening posts for intelligence gathering on technology and market trends and which were also used for R&D activities complementing efforts at home.
- 2) By means of second-sourcing and contract manufacturing with leading American and Japanese companies which forced the chaebol to comply with stringent design rules, they acquired and deepened process technology.

Although the Korean model was tremendous successful for catching-up, according to Ernst (1998), it has reached its limits. A heavy reliance on credit and an extremely unbalanced industry structure have given rise to a narrow knowledge base and a sticky narrow pattern of specialization of Korean companies in high-tech commodities that are characterized by periodic surplus capacity and price wars. Intensifying price wars will decrease export revenues, despite a possible increase in export volumes.

Korean catching-up has focused on capacity and international market expansion for homogeneous, mass-produced products with very little upgrading into higher-end and rapidly growing market segments for differentiated products and services. The focus has been on consumer electronics and components with limited emphasis on industrial electronics, such as in the more design-intensive sectors of the computer industry. This leaves Korean electronics firms very little room for price increases so that there is a constant squeeze on their profit margins with the result that the funds required for continuous upgrading may dry up.

At the same time, there is a drastic change in the rules of competition: cost reduction needs to be combined with speed-to-market. Suppliers have to face most of the inventory risk and the time-to-market pressure by adopting just-in-time delivery schedules. This requires a significant increase of upgrading investments at a time of pervasive price wars.

The weakness of Korean firms translated in a limited capacity

to develop new products and markets. Korean firms in international semiconductor markets only competed in the segment of DRAMs. The heavy dependence of revenues from the demand for computer memories made the Korean semiconductor industry highly vulnerable, while investment thresholds continue to grow rapidly. The minimum efficient scale for producing DRAMs is now more than \$1 billion of annual sales. This implies that only firms that have reached the critical threshold of 5% of world production can compete successfully. The very high entry barriers are due less to their R&D intensity than to an explosive combination of high capital-intensity, very high economies of scale and an extreme volatility of demand. Aggressive price reductions have turned the DRAM business into the "bleeding-edge" of the semiconductor industry with all leading players experiencing huge losses.

In Korea the growth of companies has occurred through *octopus-like diversification* into many different and unrelated industries rather than through an accumulation of knowledge through industrial upgrading. Each time a chaebol has reached the limits of easy capacity and market share expansion for a particular product, it moved on to a new product group that promised rapid market expansion without much scope for an upgrading into higher-end market niches where premium prices could be reaped. The top five chaebol are operating in some 140 different sectors each.

This failure to upgrade is one important reason of Korea's vulnerability to the Asian financial crisis which has reduced the capacity to generate enough foreign exchange to service their huge foreign debt.

Furthermore, Korea's semiconductor industry was based on an extremely weak foundation in terms of the materials and production equipment required which in the early 1990s had to be imported for 70% and 90% respectively. This dependence may be reduced by forming joint ventures with American and Japanese electronics firms.

Another basic weakness is Korea's very unbalanced international trade structure in semiconductors. Korea keeps exporting more than 90% of its total output of memory chips, while at the same time importing more than 87% of its domestic demand for microprocessors. This extreme imbalance between supply and demand makes it very difficult to broaden and deepen forward and backward linkages within the electronics industry and to place it onto a more viable basis.

In this sense Korea's semiconductor industry represents a modern version of the classical monoprodukt export enclave with minimum linkages with the domestic economy.

The key issue for the Korean semiconductor industry is whether or not it will succeed in broadening its product portfolio and move beyond computer memories. The prospects are not favorable.

Since the early 1990s, there is a disturbing change in the destination of Korea's exports away from the demanding American and European markets towards an increasing reliance on emerging markets within the region. Between 1991 and 1996, the combined share of North America's and Europe's markets decreased from almost 51% to 41%. (This holds for Taiwan, Singapore and Malaysia too.) The implication is that there is a decline in competitive pressures to upgrade product performance and quality and that there is less exposure to sophisticated customers. The increase in internal-regional trade has become a liability because it provided a perfect channel for the contagion of the crisis to spread through East Asia.

Korea's overall and private sector R&D is substantially below the critical threshold level required for moving beyond the technology catching-up stage in comparison with the main OECD economies.

Moreover, Korea's quality of the R&D output, i.e. the effectiveness of technology management is outdated. Korea's innovation system is characterized by a centralized model in contrast to the progressive decentralization of R&D in Japan, the USA and Europe which benefits from continual and numerous interactions and feedbacks among a great variety of actors across all stages of the value chain.

Furthermore, Korea's public innovation system is highly imperfect. Each Ministry sets up its own program and pursues its own goals without any coordination.

Korea's educational system is poorly equipped to cope with the shift in focus to research, product design and market development. Too much focus has been placed on conformity and memorization, too little on creativity, i.e. the identification of new problems and innovative, unconventional solutions. Korea's low level of higher education has been a major drag on R&D productivity in Korean firms.

A particularly disturbing feature of Korea's development model is the high debt-equity ratio of Korea's chaebol of 4 to 1,

while for the sake of comparison, Taiwan's ratio was much lower between 1.60 and 1.80. Korea's total debts are estimated to be twice as large as its GDP of \$500 billion. In 1996 Samsung had a debt-equity ratio of 473%. Since equity finance is more expensive than debt finance because of the need to pay a risk premium, catching-up requires high debt-equity ratios. But this makes the financial system highly vulnerable to shocks that distort liquidity and solvency.

Due to the recession in the world semiconductor market since 1996, the profitability of the Korean semiconductor industry had already deteriorated even before the Asian financial crisis. But after the crisis, as their hardship got more serious, restructuring measures such as mergers or sell-offs of some business were implemented.

In order to alleviate overlapping investments among domestic companies and to strengthen the international competitiveness of the industry, the government, influenced by the IMF, engineered "Big Deals", a grand design of merger and business swaps among the five largest conglomerates.

As part of the plan, a merger between Hyundai Electronics and LG Semiconductors has been promoted with Hyundai taking control of the merged company. This resulted in only two major companies, Samsung Electronics and the newly merged company, which dominate the Korean semiconductor industry.

Meanwhile, restructuring of the industry proceeded in other countries. Micron Technology acquired the memory chip business of Texas Instruments. Throughout Japan, Europe and Taiwan, many changes such as divestments and downsizing have occurred. After the merger between Hyundai and LG, four major companies, Samsung Electronics, Micron Technology, Hyundai/LG and NEC-Hitachi control about 75% of the international DRAM market.

During 1998, Korean exports of semiconductors in dollar terms decreased because of the fall of prices due to the oversupply of DRAM chips in the world market. Accordingly, domestic manufacturers whose profitability worsened had to accelerate their business restructuring by downsizing, spin-offs, sell-off of foreign subsidiaries and foreign capital attraction.

The first year after the currency crisis, i.e. from November 1997 to October 1998, in the semiconductor industry domestic demand decreased by 14.6% and exports by 3.8%. In the second year after the currency crisis, i.e. from November 1998 to October 1999, domestic demand increased by 14% and exports by 13.3%.

From November 1998, exports of semiconductors began to recover. Particularly, the international price rise of memory chips contributed to an increased rate of over 10% for both production and export. While demand for semiconductors increased due to the continuous increase of new PCs' memory requirements and expanding distribution of low-priced PCs in the world market, supply has relatively decreased due to continuous restructuring of the world semiconductor industry. As a result, the US spot market price of 64M DRAM chips, which had fallen to the \$4 level in early July 1999, rose to over \$10 in October. Specifically, when significant portions of production were halted by the earthquake in Taiwan in mid-September, the price of semiconductors once soared to \$21 although the price soon returned to its seemingly more normal level of \$12-13.

Though Korea and Taiwan share many similarities, the two countries have chosen very different approaches. Taiwan's industrial policy did not discriminate against smaller firms, while the Korean government directed credit to a handful of chaebol. In Taiwan small and medium-sized enterprises have been the main carriers of industrial development. Taiwan's industrial policy is focused on flexibility and competition and Taiwan made it easy for new companies to get started and for established ones to fail. Taiwan's firms found it more difficult to raise capital for large-scale volume production and this forced Taiwanese firms to respond more quickly to new market opportunities. Taiwanese firms cover a much broader range of products than Korea: they are strong not only in design-intensive, differentiated products but also in homogeneous products, which play a much less important role than in Korea. Taiwanese firms avoid vertical integration and prefer to rely on complex international production networks. The fact that key components and engineering talent have to be purchased on the open market enhances the flexibility of Taiwanese firms. A heavy reliance on internal sourcing, as in Korea, might obstruct the capacity for quick response.

While the Korean model was conducive to catching-up, it failed to develop a broad domestic knowledge base that is essential for industrial upgrading. Korea has not used its savings productively in terms of increasing its capacity to learn and innovate. Compared with other developing countries Korea's model has given rise to a wastage of capital in this sense that its marginal capital output ratio in the range of 4 to 5 is too high, judged by its average savings rate of 30% and its average annual growth rate of 8%. The primary goal of the chaebol was growth (or sales) maximization rather than

profitability in order to achieve at top speed a critical minimum size at which the government would be unable to allow insolvency or bankruptcy. Firms raced to the brink of bankruptcy with one eye fixed on the government to be saved from going over the edge. The result was a persistent tendency toward over-capacity.

At this very moment, Korean companies are revving up R&D activities and diversifying business. They are boosting their market position with value-added chips, solidifying a niche position. Samsung has extensive plans to construct Samsung Valley by constructing a new 1M-square-meter semiconductor production complex in Hwasung, near its Kiheung headquarters. Its technological focus aims to the development of 0.10 μ m design rule by 2001. Riding on the IT boom, Samsung and Hyundai began a drive to flash memory chips which are forecast to emerge as the second largest sector of the memory chip market in 2000. Samsung's latest developments include the promotion of system-on-chip. The year 2000 is likely to see the launch of foundry services.

Concluding, maintaining their edge in memory devices, expanding in the non-memory arena and entering the realm of foundries, for Korean companies the heat is on.

14.6. Position of China.

The electronics market in China has enormous growth potential. Today it is only one-tenth the size of the US electronics market, but over the next 15 years this picture will change dramatically. The size of the PC market in China is projected to double in five years and to equal the US market by 2010. The telecommunications, computers and semiconductor markets in China are experiencing tremendous growth rates, with many of these sectors' estimated growth rates ranging from 20% to 40% annually over the next 15 years. In semiconductors China could potentially become the world's second largest market by 2010.

Fact is that major barriers remain to foreign participation in the expanding electronics market in China. China has indicated that the electronics industry is a pillar industry so that it is important to its national economic development and therefore is treated as a strategic sector. To this end China is heavily recruiting foreign investment from device manufacturers that could in turn provide sales opportunities for semiconductor equipment and materials suppliers. China's central government allows regional and local authorities in special economic zones the latitude to provide investment

incentives such as tax abatement and to institute internationally recognized common business practices. Although much of the semiconductor industry investment to date has been in test and assembly facilities, China is increasingly targeting advanced wafer fabrication technology.

China is still confronted with national security controls set in place during the Cold War designed to restrict advanced dual-use technology exports to rogue nations. These controls have not been substantially liberalized in the past seven years. Although China is not considered a target country in the Wassenaar Arrangement of 1995 which governed sensitive exports in the post-Cold-War world, (with strict controls on technology shipments on target countries such as Iran, Iraq and Libya) exports of controlled equipment are still subject to licensing. While the EU and Japan require export licenses for China, they do not view those licenses as de facto export restrictions. Conversely, although the US government has not imposed new controls, under attack by the Congress it is turning down more licenses. This will hamstring the ability of US semiconductor equipment suppliers to fully participate in the Chinese market, unless policy makers in the Clinton Administration can be convinced that vital economic interests are at stake.

In October 1997 China announced to join the Information Technology Agreement (ITA) negotiated under the auspices of the WTO and thereby to eliminate China's tariffs on semiconductors. The ITA can be viewed as a free trade zone for the IT sector. The ITA radically speeds-up the elimination of tariffs on IT by scheduling their complete elimination for about 90% of world IT trade by 2000.

A rapid elimination of tariffs and other barriers to trade is in China's own self-interest because the competitive dynamics of HT industries demand open markets and it will promote the development of China's own industry. Policies to promote national champions behind protected national boundaries will lead to slower growth of IT activities and will create laggard domestic IT industries compared to competitive industries operating in open markets.

If China wants to be a part of the global information society it will need to eliminate rapidly its tariffs. The current Chinese tariff of six percent on imports on integrated circuits offers little protection to domestic firms that are employing lower level manufacturing technologies while competitors in other countries are using higher level

process technologies.

When a government chooses to try to develop its IT sector behind tariff walls, the resulting higher prices domestically will lead to lower demand so that lower tax receipts could easily offset the increased revenue from the tariffs.

The six percent duty merely acts as a tax on downstream industries, such as PCs, that are forced to pay more than their international competitors for leading edge ICs. The duties not only do not provide protection for the IC industry, but they add an extra tax on the downstream PC and other industries making them less competitive. Rapid tariff elimination would also reduce the incentive for importers to smuggle products from Hong Kong.

Moreover, tariff elimination contributes to the transfer of technology. Granting foreign suppliers trading and distribution rights enables direct engineer to engineer contacts between suppliers and customers in designing advanced semiconductors in electronics systems and this promotes technology transfer. In this respect too it is in China's interest to eliminate its tariffs.

If there is any variation in the staging of tariff reduction the tariffs on inputs should be eliminated first. This is because any tariffs imposed on inputs will be an added cost for every downstream product using these components. According as China phases out its IT tariffs to implement the ITA, it should ensure that its tariffs on semiconductors and computer parts are eliminated first in order to avoid the negative consequences for its downstream electronic producers.

Maintaining a presence in China requires the commitment of foreign companies to contribute to technology and know-how to the Chinese people. To stay in the good graces of the government technology companies must give their expertise back to the local market. The primary purpose is to accelerate the learning curve of the companies' top local managers. Therefore, for foreign companies competing in China in-house MBAs seem to be the rigeur these days. Offering these degrees free of charge to the executives of their major clients helps the companies breed customer loyalty and expand market share.

On May 24, 2000, after some of the most nail-biting days Washington had seen in years, the US House of Representatives voted to give China most-favoured-nation trading status on a permanent basis, known as Permanent Normal Trade Relations

(PNTR) by a majority of 237 to 197. This will set the stage for China's membership in the WTO. Passage by the Senate, which should vote soon, is considered much more of a certainty. High-tech companies said the vote was the most important one this year to expand markets in the most populous nation in the world. The high-tech industry has driven the booming US economy, accounting for about 44% of recent US growth. The ability to sustain that growth is dependent upon fair and open access to world markets, including China. China is a huge, critical and fast-growing market for all products and services. Telephone use is expected to grow from 12% of households to 22% by 2003 and the PC market is growing twice as fast as the world average and is expected to be the world's second-largest by the end of 2000.

In the US, unions, the most powerful anti-PNTR lobby, spent \$2m on advertising and blitzed congressmen. However, commercial interests fought back. In addition to a massive advertising blitz, big US companies encouraged their employees to write letters to congressmen.

Normalising trade relations with China may help change the ambivalent attitude of Americans about free trade. This may be the most important domestic legacy of the PNTR vote. The vote is important because it has shown that, in contrast to Bill Clinton's failure to gain fast-track trade-negotiating authority in 1997, which has cost America credibility in trade talks, trade bills can actually be passed by Congress. Even the most ardent free-traders were beginning to question this. This success reflects a new cohesion between the administration, pro-trade lawmakers and the business lobby.

By joining the WTO, China will become subject to the Agreement on Trade Related Intellectual Property rights (TRIPs), the best vehicle to combat software piracy. It has been estimated that in 1998 95% of the business applications software used in China was pirated, depriving the software industry of nearly \$1.2 billion in licensing revenue. Already, China has enacted patent, copyright and trademark laws, but their credibility requires strengthened enforcement.

The Chinese government has agreed to push its state-invested enterprises, which control a significant share of the trade in electronics goods into and out of China, to make purchases on the basis of commercial considerations. Without such an agreement, there would be a risk that other state-invested enterprises (i.e. those making PCs) would be encouraged by Chinese officials to buy from domestic chip suppliers.

China agreed to adopt the Information Technology Agreement, which will eliminate its customs duties on computers and peripherals, currently averaging up to 15%, by 2003.

Restrictions on "trading rights" (the ability to import and export from China) will be eliminated. The current system forces outside producers to sell through Chinese distributors and provide after-sales service through a domestic Chinese entity. The inability to deal directly with end-users has been a particular problem in the chip industry, where the design and development of application-specific chips requires extensive contact between chipmakers and the ultimate end-users of the chips.

It may be too much to hope that China will completely avoid dumping semiconductor devices on the rest of the world, but it has at least agreed to be subject to the same anti-dumping regulations as other countries.

China should be congratulated for realizing they need to make changes in order to foster a high-tech industry, but they must realize that their biggest challenge has yet to come: enforcing the rules to which they have agreed.

14.7. The Position of Israel.

In Israel high technology is increasingly replacing traditional industrial production. Israel is one of the world's five top countries when it comes to investment in research as a proportion of GNP. After the USA, which is currently registering the largest number of new high-tech companies, Israel with over 3000 high-tech companies is an incubator with support centers for start-up firms scattered all over Israel. The whole success of the Israeli high-tech sector has been based on an alliance with the major American players. Israeli companies raised two-thirds of their funds abroad in 1999, largely from American stock offerings. However, the money came with a condition. Almost all venture capitalists are requiring new companies to establish their headquarters in the US, as a prelude to a Nasdaq offering or a takeover by an American multinational.

"From oranges to semiconductors" is the slogan that aptly sums up the dramatic change in Israel's export policy. Now, 80% of industrial exports and a third of total exports are high-tech products.

In 1997, electrical industry exports of \$6.7 billion consisted of:

Telecommunications	39.2%
Industrial and Medical Systems	24.4%
Defense Systems	17.4%
Components	19.0%

It is probably true to say that the military is very much the driving force of technological progress. Following the Six-Day War in 1967 and the subsequent embargo which has heavily endorsed by France, Israel was forced to rely on its own strength and develop its own high-tech products.

The result was a massive jump forward in a wide range of areas, including defense electronics, image processing technology, radar and telecommunications, process control and anti-missile systems.

Although the Israelis are very talented when it comes to developing products and technology, they lack the right management culture to become global players. This explains the importance of working with globally active marketing companies in joint ventures.

15. Final Conclusions.

It is very difficult to make the right forecast in the semiconductor market, because demand and supply has to be forecasted. On the demand side one needs to know how many PCs will be sold, how many telephones and how many chips are required. On the supply side there is the need to know how many fabs are going to be incorporated in this year and the year after that. On the demand side there are no great mistakes, but there are a lot of mistakes possible on the supply side. The supply side is a function of the amount of capital that needs to be invested, the yield estimate which is difficult to predict and the chip size and the number of chips that can be produced on one wafer.

After a brief return to excess capacity in DRAMs at the start of 2000, demand for memory is expected to surpass the world's supply in the second quarter and a shortage may come about for the next two years. From Seoul to Silicon Valley, high-tech companies around the world are struggling with an unexpected problem: surging global demand for electronic things, especially cell phones, digital cameras and networking gear, is outstripping the capacity of the world's semiconductor factories to produce enough parts. That is leading to an acute shortage of memory chips, driving up manufacturing costs. Some companies are already paying from 4 to 10 times normal prices

for certain cell-phone parts. So far the big companies have resisted passing the increased costs along to their customers. But if the shortages don't ease up, prices on some industrial and consumer goods could start to reflect the strain.

The parts shortage springs from several events.

1) Over the past three years, as the chip industry suffered one of its worst slumps on record, manufacturers sharply curtailed spending on new plants. Chip users were partly to blame: they imposed relentless cost cuts on their chip suppliers, who in turn took that reduced income out of their own capital investment and underinvested in capital in 1999. They were caught by surprise by the strength of demand in the past six months. In September 1999, investments by chip companies started to climb again, but the damage was done. Adding capacity takes 12 to 18 months, so that today's shortages will likely get worse. Although the parts shortage is just starting to bite into corporate operations because the higher prices of key components are eating into profit margins, it is shifting the balance of power between manufacturers and suppliers. With demand racing ahead of supply, the component makers are almighty. They can actually determine a manufacturers's market share.

2) Fearful of losing market share, most manufacturers aren't passing their rising costs along to consumers. Even if consumers don't suffer price hits, rising component costs are changing the dynamics of the electronics industry, turning former winners into losers and vice versa. E.g., Samsung saw its earnings quadruple in the first quarter of 2000.

3) The parts drought has not hit all players equally hard due to smart planning strategies. Large long-term contracts with chip producers may avoid spot shortages. Finding more sources for parts over the Internet is another strategy. Re-arrangement of manufacturing so that parts can be swapped from slower-selling cell-phone models to more popular ones is a clever move.

Overall, those with the fattest market share have been the best insulated and the top-tier players get all the chips they need.

The present shortage has triggered a new round of capital investments by chipmakers of \$50 billion in 2000. But much of that new capacity won't come on line for at least two years. In the meantime, manufacturers will have to beg and borrow to keep the assembly lines moving.

However, some analysts warn that chip markets become overheated by double and triple orderings of ICs and they forecast with an 80 percent probability an "elbow", i.e. a downturn, in the trend line of chips and chip-equipment sales during the second quarter of 2000.

Signs that inventories are reaching normal levels again could be a first sign that there is a pull-back.

Falling ratios of bookings to billings might be another sign, although caution is required with this ratio, as explained above.

Next table presents an overview of recent sales trends and projection by market share for regional markets in semiconductor devices, with dollar values in billions.

	1997	1998	1999	2000
World	\$ 137	\$ 125	\$ 168	\$172
Americas	34%	33%	33%	32%
Japan	23	21	22	22
Europe	21	23	20	22
Asia/Pacific	22	23	25	24

Source: World Semiconductor Trade Statistics, in Electronic Business, July 1999.

For the equipment market the picture looks as follows.

Equipment Sales trends by Regional Market.

	1997	1998	1999	2000
World	\$ 27	\$ 22	\$ 20	\$26
Americas	33%	34%	35%	35%
Japan	26	22	20	21
Europe	11	14	13	12
Asia/Pacific	30	30	30	32

Source: Semiconductor International, July 1999.

The common theme in industries from aviation, railroad and automobiles to semiconductors, is that their initial phase was dominated by efforts to improve performance and to lower cost. A second phase in those industries was characterized by product refinement and diversity, what is now starting to

happen in chipmaking. Companies are shifting their use of technology from lowering manufacturing costs to enhancing product lines. All these industries managed to prosper in spite of higher manufacturing costs.

Industry watchers believe the IC industry is now in the early stages of an era of consolidation, characterized by the "inverted pyramid". However, the full effects of this evolutionary trend may not be readily apparent for another five to ten years. It should be noted that the emerging inverted pyramid is IC product-specific. E.g., in the Digital Signal Processing (DSP) area², Texas Instruments held 47 percent of the total 1998 market and the top four companies held a 96 percent market share. This market share make-up is definitely "top-heavy" and therefore resembles an inverted pyramid. Other IC categories may be more or less defined by the inverted pyramid structure.

Figure 23 illustrates the inverted pyramid.

In the future most major segments will become more like the current DSP market, where the shares held by the top producers

² DSP is a foundation technology deserving the title "breakthrough" with the power to transform broad areas of the electronics industry. The DSP is a single-minded specialist dedicated to a single group of tasks, racing through a smaller range of functions than a more general purpose microprocessor. The goal of DSP is to use the power of digital computation to manage and modify the signal data permitting an exactness of measurement and control impossible in analog systems. When the DSP has finished its job, the digital information may be turned back into an analog signal that is better than the original. DSP chips are engineered to handle enormous streams of real-world information, such as images and sounds and process them in real time. Its impact is being felt in applications as diverse as stereo systems, cars, PCs and cellular phones. Its functions include filtering noise from a signal, removing unwanted interferences, amplifying or suppressing certain frequencies, or make internal organs stand out more clearly in medical CAT scans. DSPs can restore vintage jazz recordings to their original clarity and enable satellites to pick out terrestrial objects as small as a golf ball and help squeeze more conversations onto crowded airwaves. The DSP literally performs hundreds of millions of operations per second at lightning speed. The market for DSP chips is growing at twice the rate of the semiconductor industry as a whole. The PC era was all about data processing, but now the post-PC era of signal processing is entering. By 2010, every microprocessor will have DSP.

leave very little for remaining competitors. The most significant effect of the future inverted pyramid situation will be the inability to second-tier companies or startups to break into the top rankings. The barriers to entry will be too formidable for new startups or second-tier companies to overcome. Such barriers include financial resources, process or design capabilities, patent protection, etc. Thus each major IC product segment ultimately ends up in the control of a few companies.

The message to the large IC producer is that in order to have a good chance of being successful in the future he must be a leading supplier today.

As the competitive framework within each IC product segment evolves toward a few major suppliers, pricing pressures will lessen and increased profitability for the leading companies in each key product area will result. The strong will get stronger.

Next table presents the 1998 rankings in key IC product segments which represent almost two-thirds (65%) of total IC industry sales of \$ 109 billion in 1998.

Product segments	Number of firms	Market share	Inverted tendency
DRAMs	6	77%	High
Flash Memory	6	81%	High
32-/64-bit MPUs	4	90%	High
Analog	6	52%	Low
Pure-Play Foundry	4	90%	Moderate
Standard Cell	6	90%	High
MOS PLD	6	90%	High
DSP	4	96%	High

Source: IC Insights, Channel Articles, 11 January 1999, Vol. 12, No.6.

It is expected that the number of major players within each IC product category and their market shares will continue to display the inverted pyramid characteristics.

Not all of the eight categories listed are expected to show the same degree of inverted pyramid tendencies, as is shown in the final column. Since the analog market is so diverse in

product make-up as well as end-use applications, there is more room for companies to select and be successful in various niche markets within the analog category. This is evident from the relatively low 52 percent market share held by the top six producers.

Therefore, over the next five years consolidation through mergers and acquisitions may characterize the industry. However, disintegration tendencies are also suggested in this sense that middle-sized vertical companies will not have the volume to justify continuously building new fabs and thus may become foundries or design houses.

Semiconductors have been the most productivity-enhancing, life-changing technological revolution since the harnessing of steampower in the 18th century or, in the 19th, of electricity itself.

It may not be long before the semiconductor industry plateaus. The pace of transistor integration will decline and manufacturing costs will begin to soar. In a more mature industry, growth will almost certainly come from refined products in more diversified lines. Information storage will keep moving forward. Even in the semiconductor industry, maturity can be a splendid asset by giving computer architectures and software time to begin assimilating the great leaps in chip performance.

There are signs of two big changes.

- 1). Within the semiconductor industry itself. Chips have become just any other commodity. From the point of view of national economies, it matters little where they are made, provided that they are available to be cheaply bought. What matters more is how they are subsequently used.
- 2). For the first 20 years or so of micro-electronics, the applications for the new technology seemed obvious. The potential applications seemed as boundless as the human imagination. But the trouble is that the imagination does have bounds. The computational power has outstripped useful applications for it. E.g., initially people were reluctant to buy Microsoft's new operating system, Windows 95, which required more memory than most home computers possessed. And consumers seemed to have decided to forgo the marginal improvement the software provided.

Moreover, the consumer-electronics industry must now struggle to dream up new "killer applications" as lucrative as personal stereos and video recorders.

The computer is now in the early throes of a new phase of its

revolution, as it becomes more an instrument of communication, less of computation. A machine that transforms communication impinges far more radically on people's lives than one that transforms computations. It is people's willingness to embrace it that matters most.

In any case the semiconductor business is about to go through a period of wrenching change.

A final prediction is that Japan will continue to fight neck-and-neck with the USA for number one position, but their cumulative relative weight will be progressively reduced. However, for the very next future the market share for Japan and North America is expected to remain fairly constant. The major change will be in the relative positions of the Asia/Pacific region and Europe.

By the start of the decade Asia/Pacific will probably overtake Europe to become the third largest semiconductor producer. Europe although in fourth place, will have a bigger market share than today, which is expected to grow to 15 percent during this decade.

China is expected to become one of the largest markets in the world. China is currently estimated to be an \$8 billion per year semiconductor market. The PC market alone has tremendous opportunities for dramatic growth. E.g., in the US, there is one personal computer for every three citizens, in Brazil, there is one PC for every 70 people and in China, there is only one PC for every 400 people.

Globalization has become a reality in the international semiconductor industry. Interrelationships between firms have grown to such an extent that it has become totally irrelevant to use a single measure to assess the market share of the contribution of different countries/regions to the global market. There is *no single measure* of the chip market telling the whole story:

- Not world exports because they exclude sales within the market in which they are produced.
- Not sales because they exclude the internal use of chips in vertically-integrated firms.
- Market shares based on world exports differ from those based on ownership. E.g., US share in world exports in the early 1990s was 18%, while its share based on company ownership was 32%. Asia/Pacific exports to the world 38%, while it owns 19%. However, under the Semiconductor Trade Agreement of 1986 the nationality of a product had been determined by the producer's headquarters, not the location of production. Therefore, a TI chip produced in Japan was counted as American and a Hitachi chip produced in the US was counted as Japanese for the

purpose of calculating market shares.

Given the borderless nature of many operations in this industry, the era in which it makes sense to distinguish the nationality of a chip has long since passed.

The role of strategic alliances spanning R&D, product development, production and distribution has grown enormously over the past and will continue to increase functioning as the most important mechanism for technology transfer in the semiconductor industry. The advantage of strategic alliances is that there is no government money involved so that there is no requirement to share the technology with other companies how much or how little they bring to the party. In strategic alliances each of the parties will benefit from the results of the investment in technology development and are not required to share with everyone else in the country.

The number of alliances between companies is increasing and the majority of alliances is formed between companies in different economic regions. Most alliances are between companies in developed countries for the purpose of developing technologies and products, i.e., the promotion of R&D and the exchange of technology. Alliances with companies in emerging Asia are increasing and tend to be for production objectives in the form of formal joint ventures.

Next table presents figures about the change in the regional dispersion of alliances from 1981-1992.

	US-US	US-Japan	US-Europe	Japan-Japan	Japan-Europe	Europe-Europe	US/Europe/Japan/Row
1981-83	0%	0%	83%	0%	0%	17%	0%
1984-86	10%	5%	36%	3%	10%	23%	13%
1987-89	25%	14%	11%	2%	11%	17%	20%
1990-92	9%	25%	24%	0%	10%	7%	25%

The emergence of successful global alliances has the potential to shift competition away from the current, predominantly nationalistic focus to a struggle among competing global partnerships. These partnerships will likely form the basis for a series of global semiconductor "camps", each centered on the process-technology capabilities of two or three global

firms linked to a multitude of smaller, allied producers. There will be networks of companies from the USA, Europe and Japan working together. It is these networks of companies that compete with each other without government involvement. The primary axis of competition will not be between the USA and Japan, but between competing camps of global producers.

Coopetition or cooperating to compete has arrived in the industry with a vengeance. Coopetition has become common in this industry because users want to know in advance that a broad range of companies will support a given technology. This helps markets grow faster, without requiring prolonged periods to shake out competing technologies. Coopetition often involves companies agreeing not to battle in one market even as they fight like dogs in others. Companies compete on actual products and cooperate on technical standards sacrificing a degree of independence to increase the odds of success for the technology as a whole. Of course, coopetition makes antitrust authorities nervous if competitors agree not to compete. Given the steady flow of announcements of strategic alliances, partnership agreements, joint development programs and the growing number of mergers and acquisitions, the age of coopetition has gained such momentum that this business news overshadows the technology news of the sector. This new age of coopetition takes many forms which fall into three groups: equipment and materials companies are teaming up with each other on specific new developments, with their customers and with universities, consortia and other research organizations.

At first the focus of such cooperation was on precompetitive development efforts and was funded through consortia such as SEMATECH and a host of other such organizations that sprang up around the globe. Previously device manufacturers often built their own costly in-house equipment development teams for fear that an outside vendor might inadvertently share processing secrets with competing semiconductor companies.

But two primary factors fueled a change.

- * One was the reality of rising development costs of the transition to 300 mm wafer production which could no longer be absorbed into the unit price of finished chips. As development cycles shorten, high-yield processes must be implemented in manufacturing in the first place and capitalizing on the expertise of strategic partners is a useful way to achieve this goal.

- * The other factor was the rapid globalization of the industry that made obsolete the concept of competing along geographic lines.

The final conclusion is that in the future the model for the semiconductor companies will be competition with cooperation: "coopetition".

- - -

References.

- D.P. Angel, Restructuring for Innovation, The Remaking of the US Semiconductor Industry, New York, 1994.
- D.B. Audretsch and M.P. Feldman, R&D Spillovers and the Geography of Innovation and Production; The American Economic Review, Vol. 86, No. 3, June 1996.
- R.E. Baldwin, The Impact of the 1986 US-Japan Semiconductor Agreement, Japan and the World Economy, 1994, Vol.6.
- C.F. Bergsten and M. Noland, Reconcilable Differences?: United States - Japan Economic Conflict, Washington DC, 1993.
- M. Borrus and St.S. Cohen, Building China's Information Technology Tariff Policy and China's Accession to the WTO, BRIE Working Paper 105, November 1997.
- E. Brynjolfsson and L.M. Hitt, Beyond the Productivity Paradox, Computers are the Catalyst for Bigger Changes; Communicatins of the ACM, August 1998.
- Commission Communication concerning Autonomous Tariff Suspensions, Official Journal of the European Communities, C 235/2, 13 September 1989.
- A.R. Dick, Learning by Doing and Dumping in the Semiconductor Industry, Journal of Law and Economics, April 1991.
- A.R. Dick, Industrial Policy and Semiconductors, Missing the Target; The American Enterprise Institute, 1995.
- DRI/McGraw-Hill, The Globalization of the Semiconductor Industry, 1996.
- The Economist, Semiconductors, When the Chips are Down, March 23, 1996.
- The Economist 23 July 1999, How Real is the New Economy? Work in Progress.
- D. Ernst, Catching-Up, Crisis and Industrial Upgrading. Evolutionary Aspects of Technological Learning in Korea's Electronics Industry, DRUID Working Paper, No.98-16. August 1998.

- European Commission, Second European Report on S&T Indicators 1997.
- K. Flamm, Semiconductors; Chapter 5 in G.C. Hufbauer, (ed), Europe 1992, An American Perspective, Washington DC, 1990.
- K. Flamm, Semiconductor Dependency and Strategic Trade Policy; Brookings Papers on Economic Activity, 1993.
- K. Flamm, Mismanaged Trade: Strategic Trade Policy and the Semiconductor Industry, 1996.
- R.J. Gordon, Has the "New Economy" Rendered the Productivity Slowdown Obsolete, NBER Working Paper, No. ... June 14, 1999.
- B.T. Grimm, Price indexes for Selected Semiconductors, 1974-96, Survey of Current Business, February 1998.
- P.C. Grindley and D.J. Teece, Managing Intellectual Capital: Licensing and Cross-Licensing in Semiconductors and Electronics, California Management Review, Vol 39. No 2, Winter 1997.
- P.C. Grindley, D.C. Mowery and B. Silverman, SEMATECH and Collaborative Research: Lessons in the Design of High-Technology Consortia; Journal of Policy Analysis and Management, Vol. 13. No.4, 1994.
- H. Gruber, Learning and Strategic Product Innovation, Amsterdam, 1994.
- H. Gruber, Trade Policy and Learning by Doing: the Case of Semiconductors, Research Policy, Vol.25, 1996, p. 723-739.
- B.H. Hall and R.M. Ham, The Patent Paradox Revisited: Determinants of Patenting in the US Semiconductor Industry, 1980-94; NBER Working Paper 7062, March 1999.
- R.M. Ham, G. Linden, M.M. Appelyard, The Evolving Role of Semiconductor Consortia in the United States and Japan, California Management Review, Vol. 41, No. 1, Fall 1998.
- M. Hobday, East Asian Latecomer Firms: Learning the Technology of Electronics, World Development, Vol.23, No.7, 1995.

- G.D. Hutcheson and J.D. Hutcheson, Technology and Economics in the Semiconductor Industry; Scientific American, January 1996.
- D.A. Irwin, Trade politics and the Semiconductor Industry; NBER Working Paper, No. 4745, May 1994.
- D.A. Irwin, Managed Trade. The Case against Import Targets, Washington, D.C., 1994.
- D.A. Irwin and P.J Klenow, Learning-by-Doing Spillovers in the Semiconductor Industry, Journal of Political Economy, 1994, Vol. 102, No.6.
- D.A. Irwin and P.J. Klenow, High Tech R&D Subsidies: Estimating the Effects of Sematech; NBER Working Paper, No. 4974, December 1994.
- J.W. Kanz, Technology, Power and Structure: Consequences for US Semiconductor Competitiveness; International Journal of Technology Management, Vol. 9, 1994.
- C.G. Krouse, Market Rivalry and Learning-by-Doing; International Journal of Industrial Organization, 1994, Vol. 12.
- C.G. Krouse, Japanese Microelectronics: Creating Competitive Advantage by Vertical Interaction; Journal of Economic Behavior and Organization, Vol. 28, 1995.
- S. Latham, Market Opening or Corporate Welfare? "Results-Oriented" Trade Policy toward Japan; Cato Policy Analysis No. 252, April 1996.
- F.T. Macher, D.C. Mowery, D.A. Hodges, Reversal of Fortunes? The Recovery of the US Semiconductor Industry, California Management Review, Vol.41. No.1, Fall 1998.
- J.A. Mathews, A Silicon Valley of the East: Creating Taiwan's Semiconductor Industry, California Management Review, Vol.39, No 4, Summer 1997.
- J.A. Mathews, A Silicon Island of the East: Creating Semiconductor Industry in Singapore, California Management Review, Vol. 41, No. 2, Winter 1999.

National Research Council, U.S. - Japan Strategic Alliances in the Semiconductor Industry: Technology Transfer, Competition, and Public Policy, Washington D.C., 1992.

SEMATECH, The National Technology Roadmap for Semiconductors, October 1995.

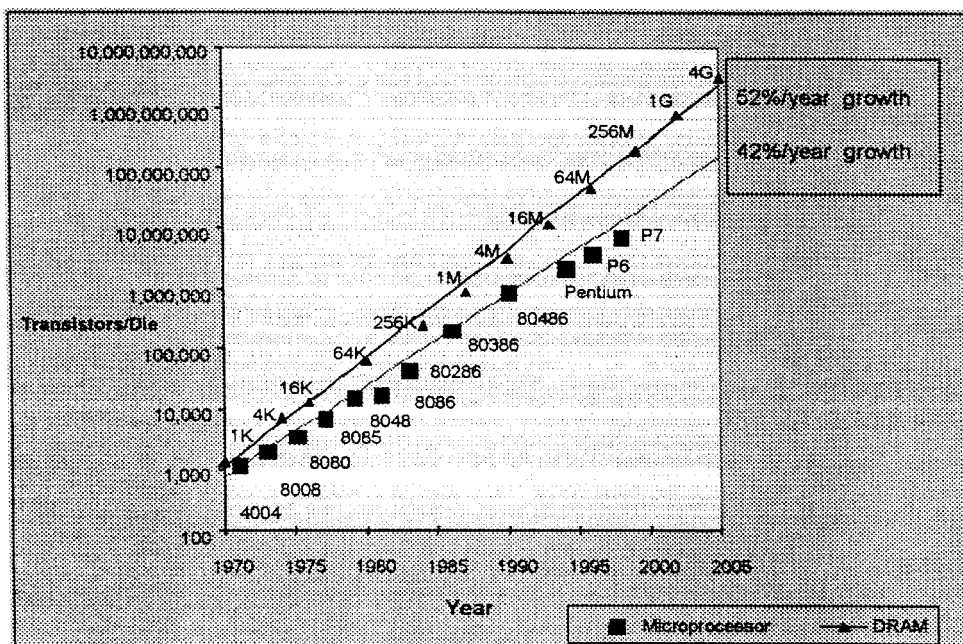
W.J. Spencer and P. Grindley, SEMATECH After Five Years: High-Technology Consortia and US Competitiveness; California Management Review, Summer 1993.

J.E. Triplett, The Solow productivity paradox: what do computers do to productivity? Canadian Journal of Economics, Vol. 32, No 2, April 1999.

J. Zysman and M. Borrus, From Failure to Fortune? European Electronics in a Changing World Economy; The Annals of the American Academy of Political and Social Science, January 1994.

Figure 1: Moore's Law

The number of transistors that can be placed on a semiconductor die doubles about every 18 months.



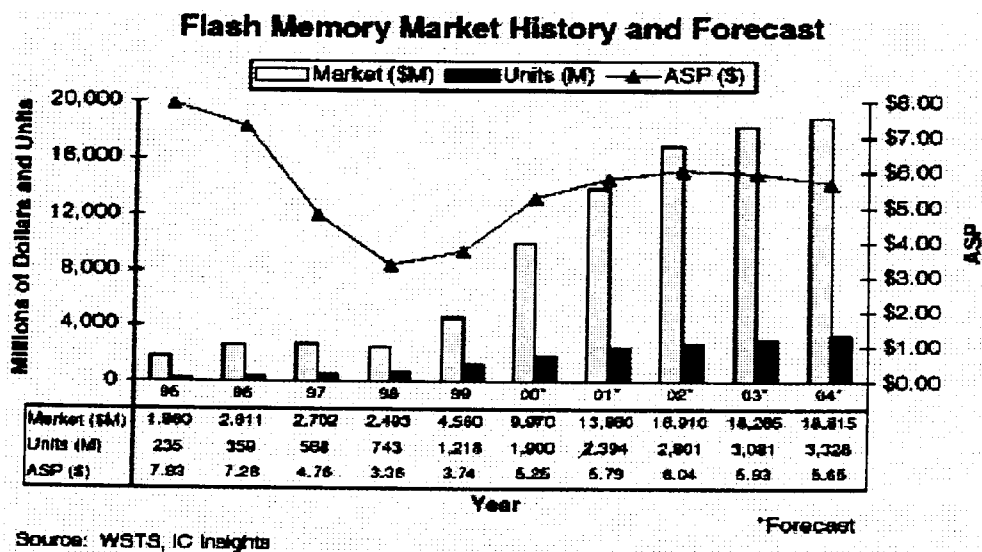
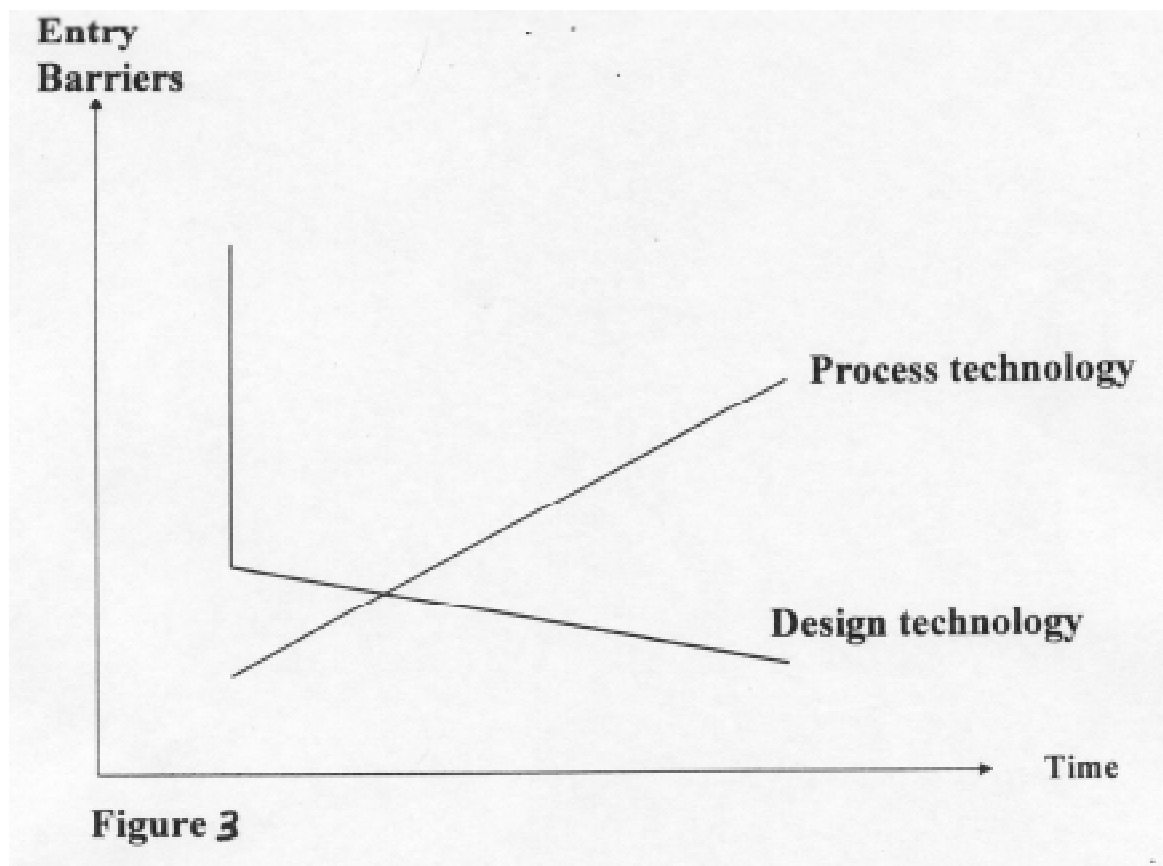


Figure 2



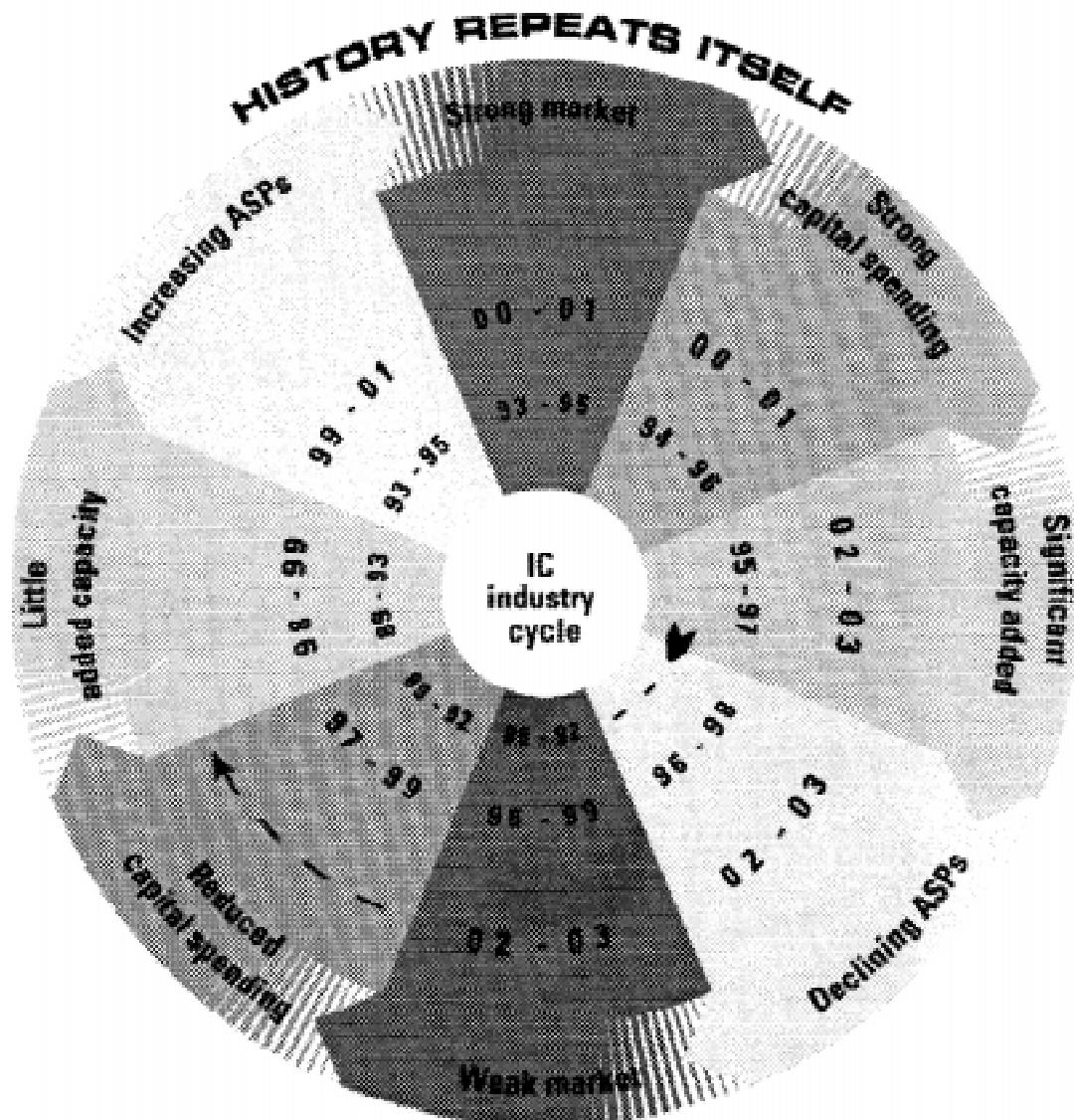


Fig. 4. The semiconductor industry follows predictable economic cycles. (Source: IC Insights)

Wafer Growth Slowing

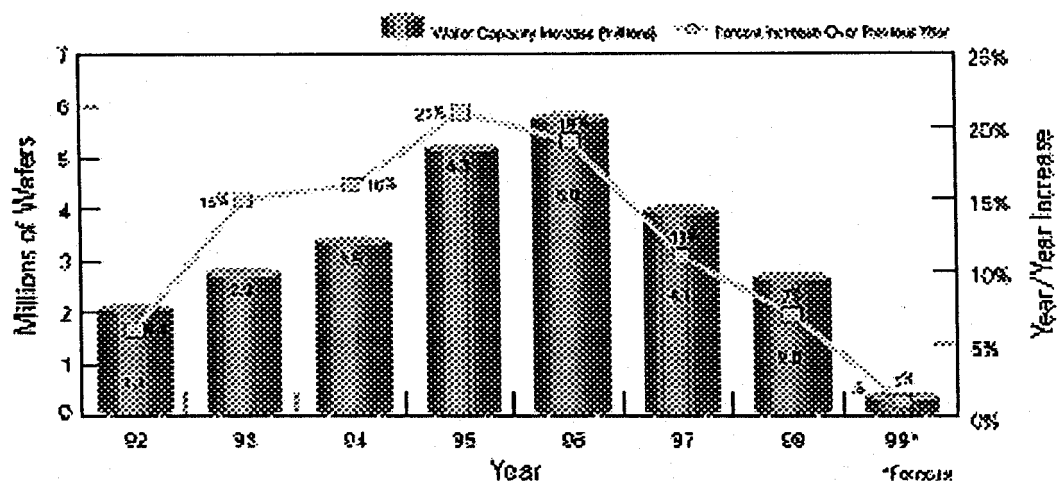


Figure 5.

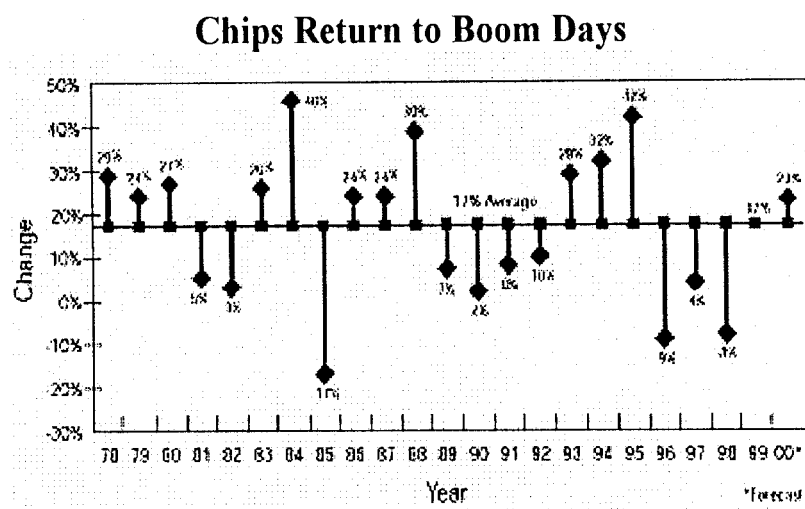


Figure 6 Worldwide Semiconductor Industry Growth Rates Compared to the Average

Source: WSTS, IC Insights

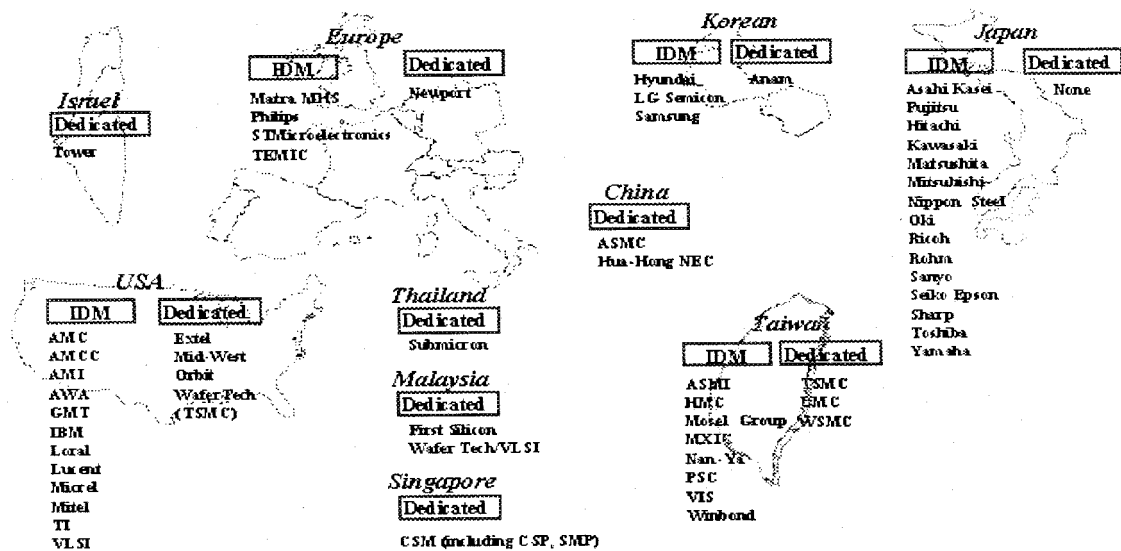
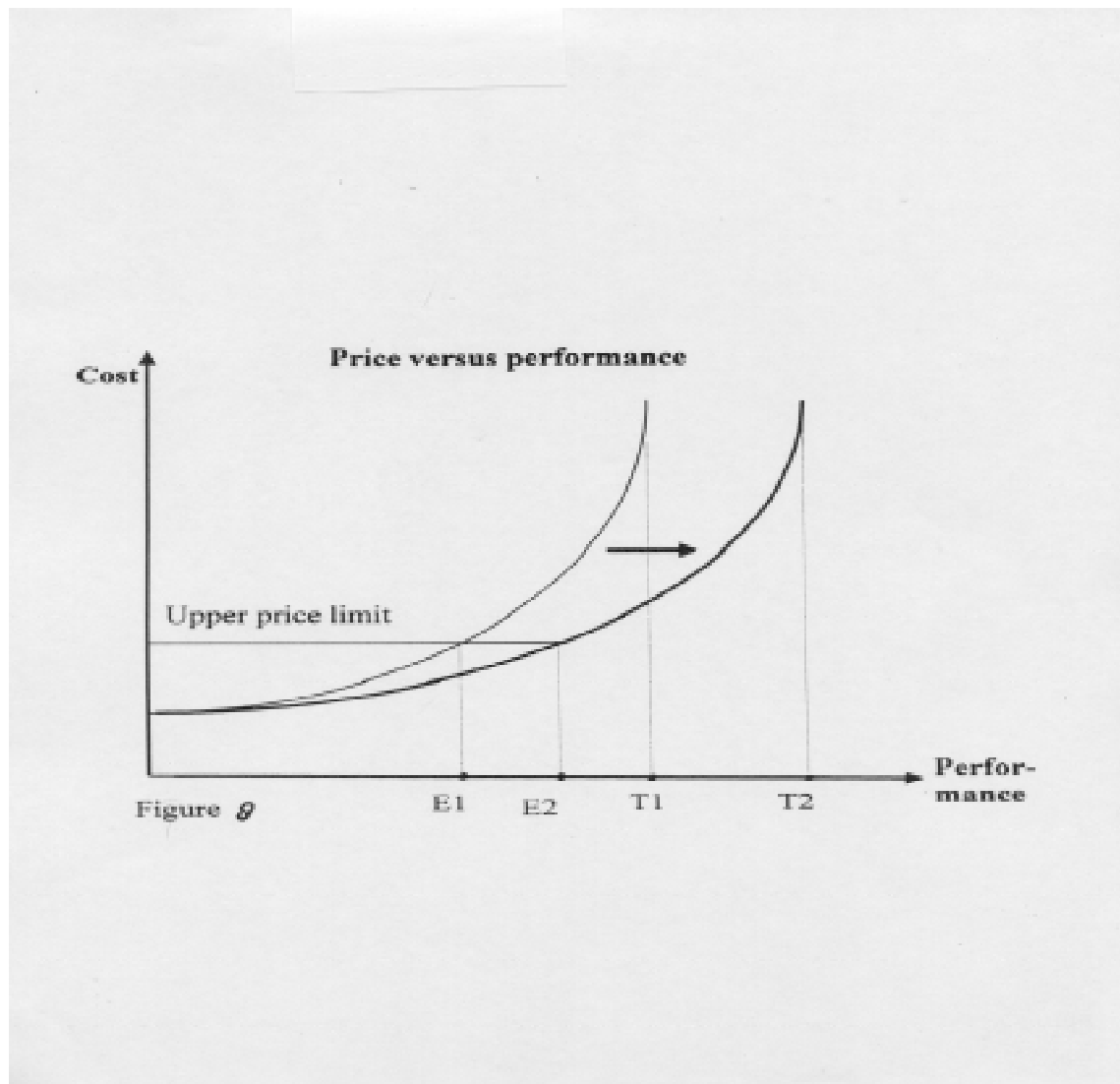


Figure 7 Global Foundry Players



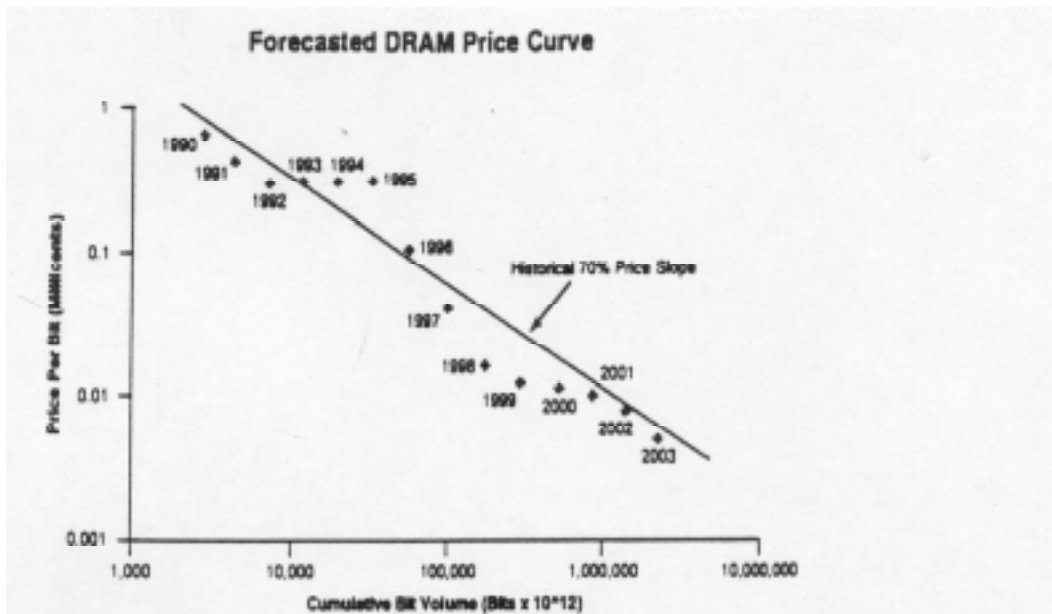


Figure 9

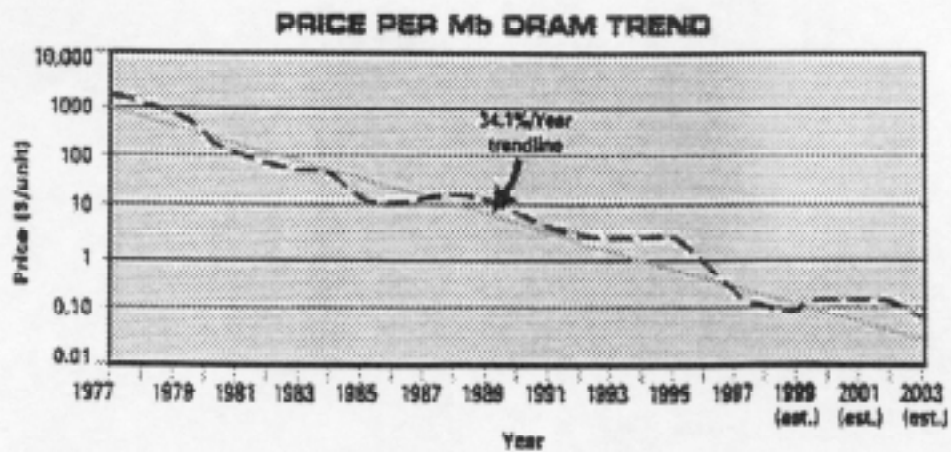


Figure 10

Table 1.—Prices and Quantities Shipped of 16 Kilobit
DRAM's

Year	Dollars	Thousands
1976	52.50	54
1977	23.00	2,008
1978	9.25	20,785
1979	6.13	53,218
1980	4.81	184,020
1981	2.11	221,473
1982	1.24	286,290
1983	1.05	296,610
1984	1.11	161,290
1985	1.34	70,920
1986		

DRAM Dynamic random access memory

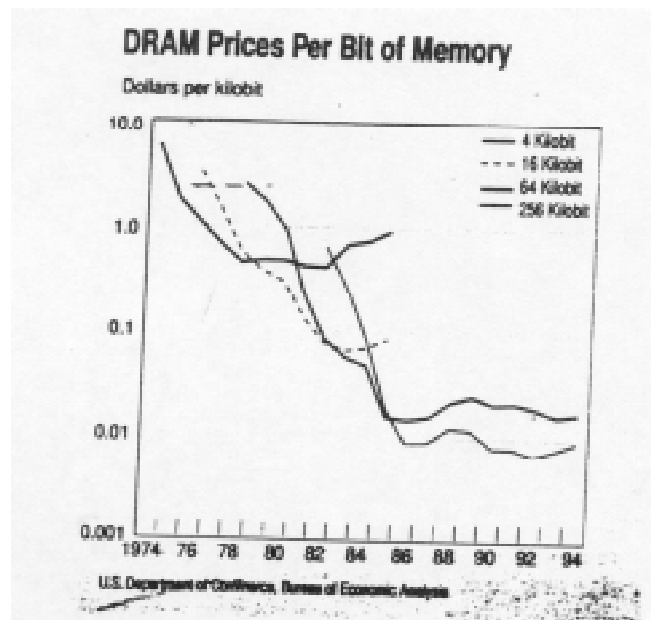


Figure 11

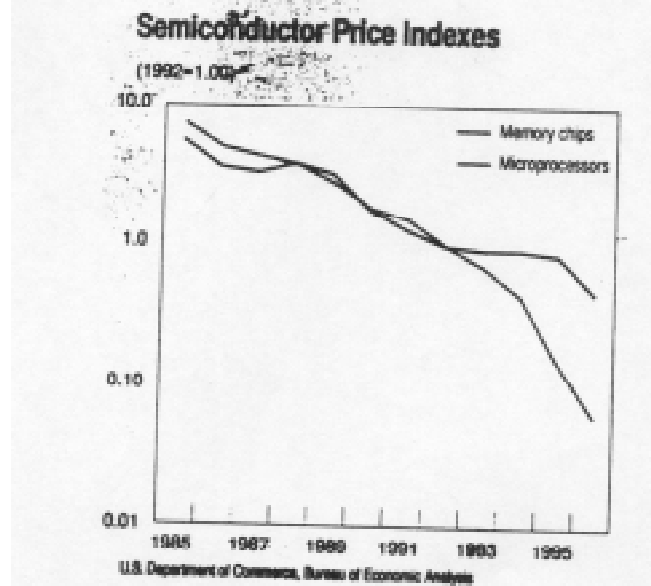


Figure 12

Figure 13. Prices for Four Generations of DRAMs, Pi Rule, 1974–89

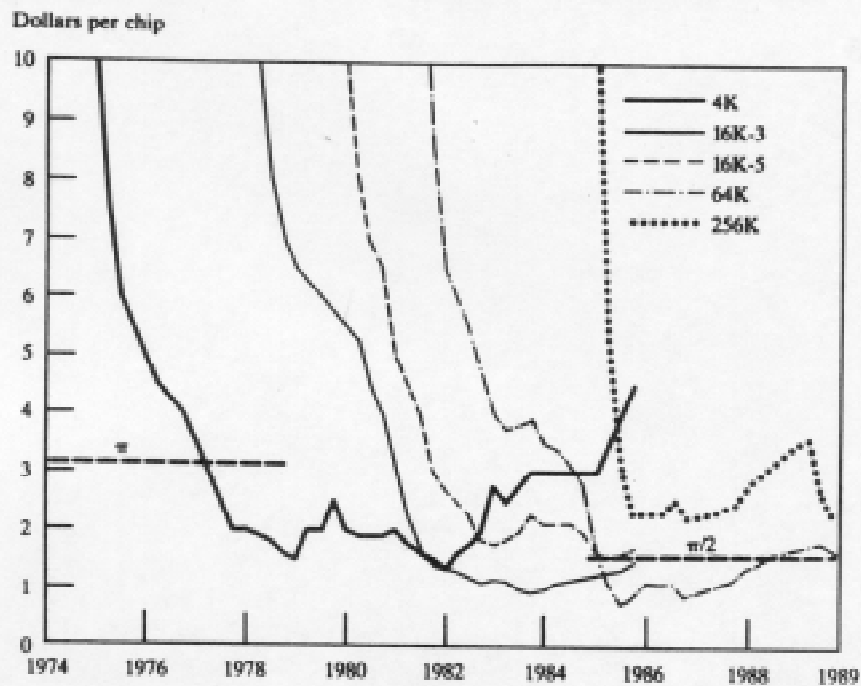
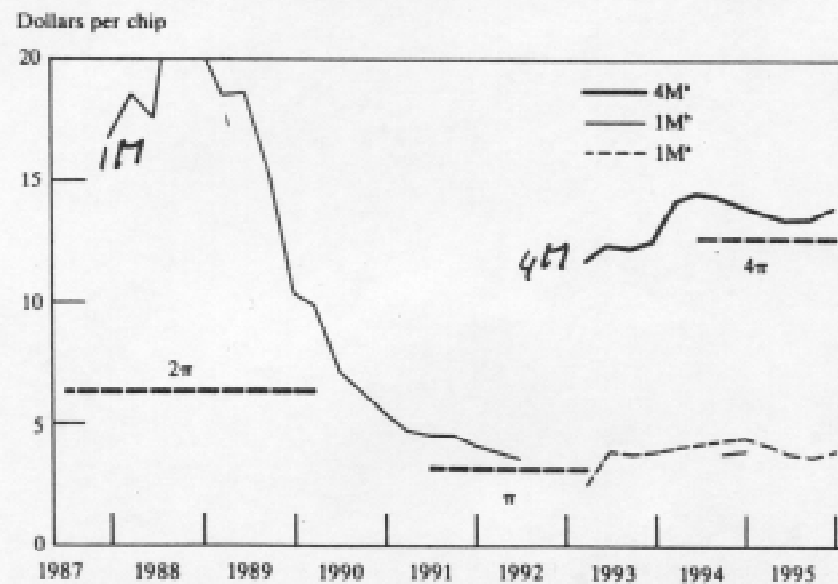


Figure 14. Prices for Three Generations of DRAMs, Bi Rule, 1987–95



This year's top 10 chip makers

Rank	1999 sales*	% change over 1998
1. Intel	\$26.14	15%
2. NEC	8.93	15%
3. TI	7.65	22%
4. Motorola	7.35	0%
5. Toshiba	6.75	16%
6. Samsung	5.8	35%
7. Hitachi	5.23	14%
8. Infineon	4.94	26%
9. STMicro	4.9	16%
10. Philips**	4.53	3%

*Billions of U.S. dollars

**Includes VLSI Technology for second half

Table 2

Semiconductor Equipment Manufacturers Top Ten










1999 Rank	CY1999 Revenues(\$M) ¹	Company		1998 Rank
1	5457	Applied Materials		1
2	2634	Tokyo Electron Limited		2
3	1430	Nikon		3
4	1276	ASM Lithography		7
5	1210	Teradyne, Inc.		4
6	1049	KLA-Tencor		5
7	955	Advantest		6
8	894	Lam Research Corporation		8
9	751	Canon		9
10	743	Hitachi Ltd.		10

Table 3.

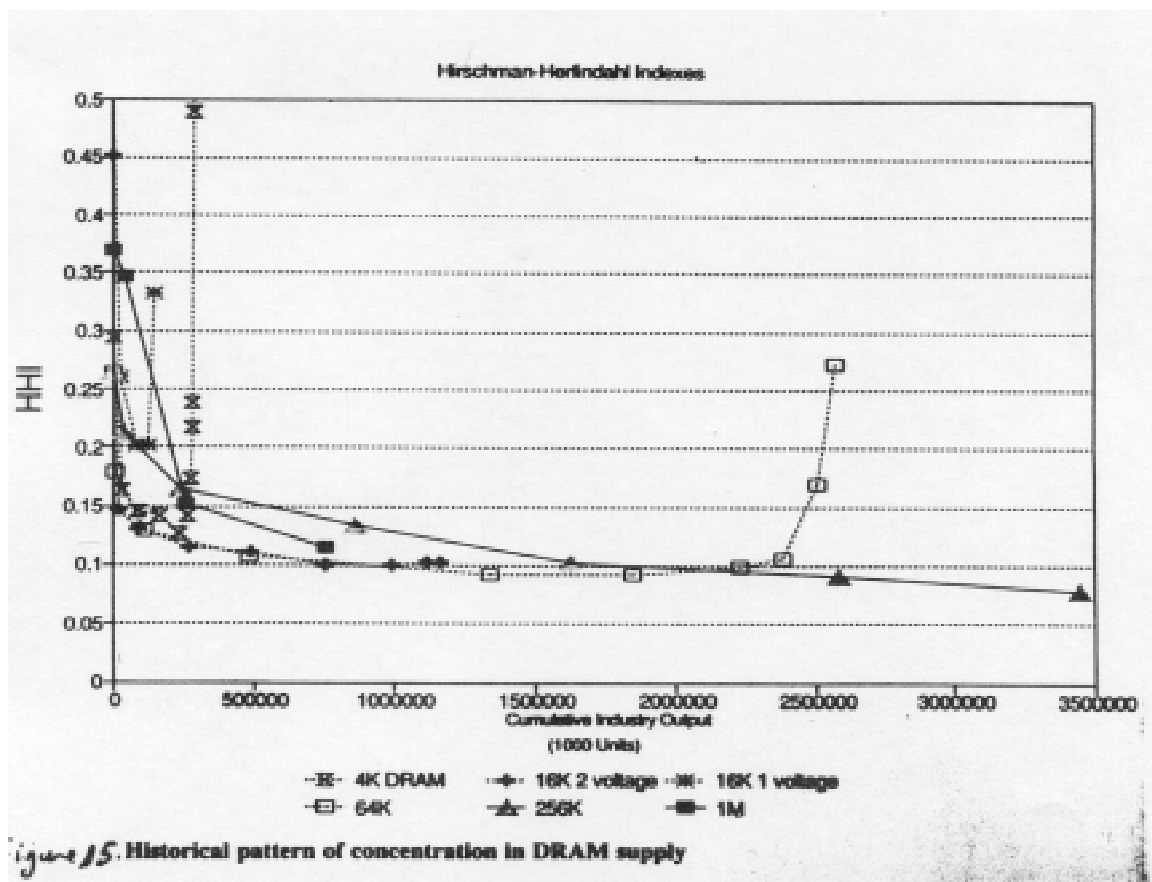
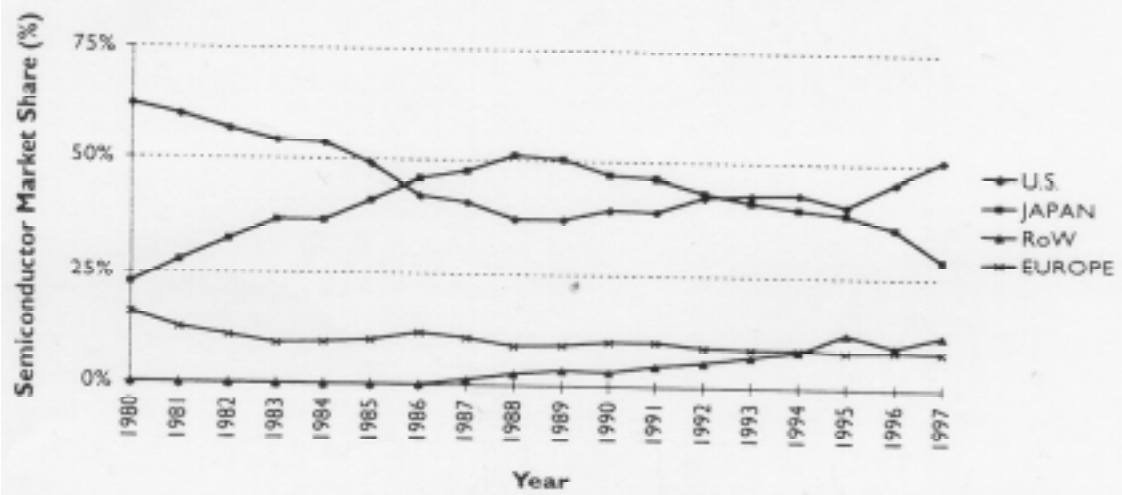


FIGURE 16. Worldwide Semiconductor Market Share, 1980-1997



Source: SIA, 1997 Annual Databook; Integrated Circuit Engineering Corporation (ICE), Status A Report on the Integrated Circuit Industry, 1980-1993.

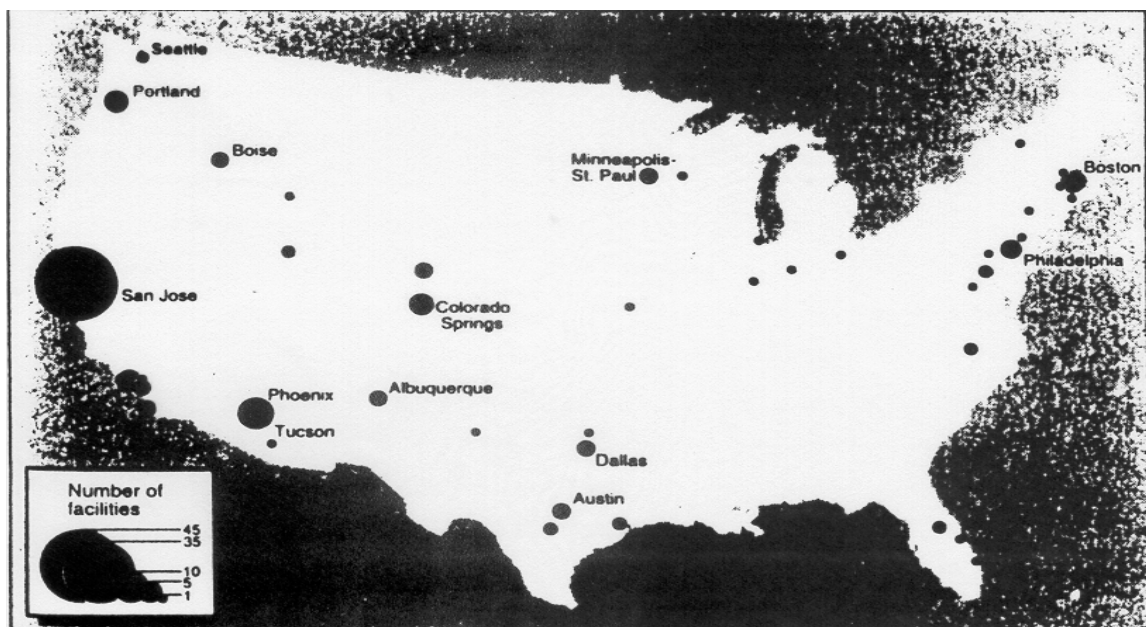
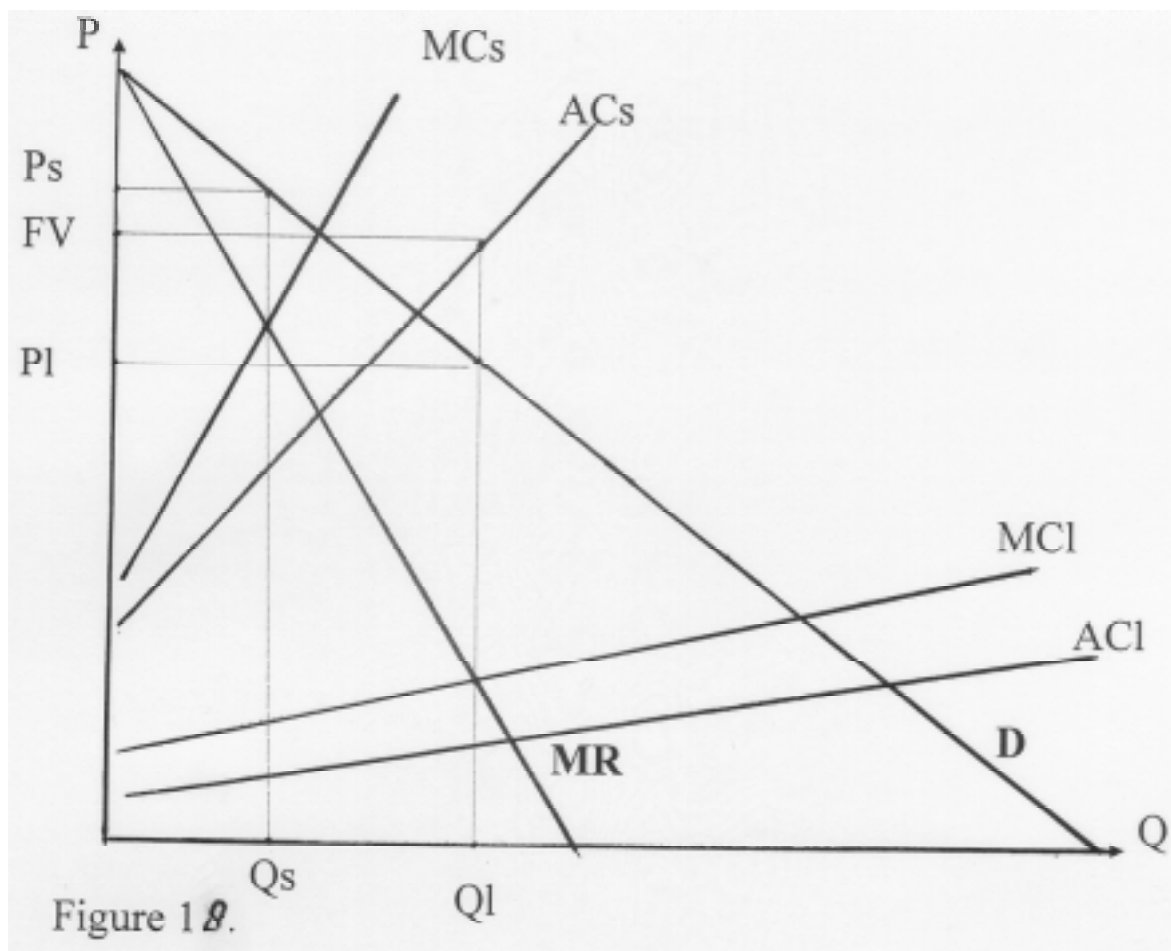
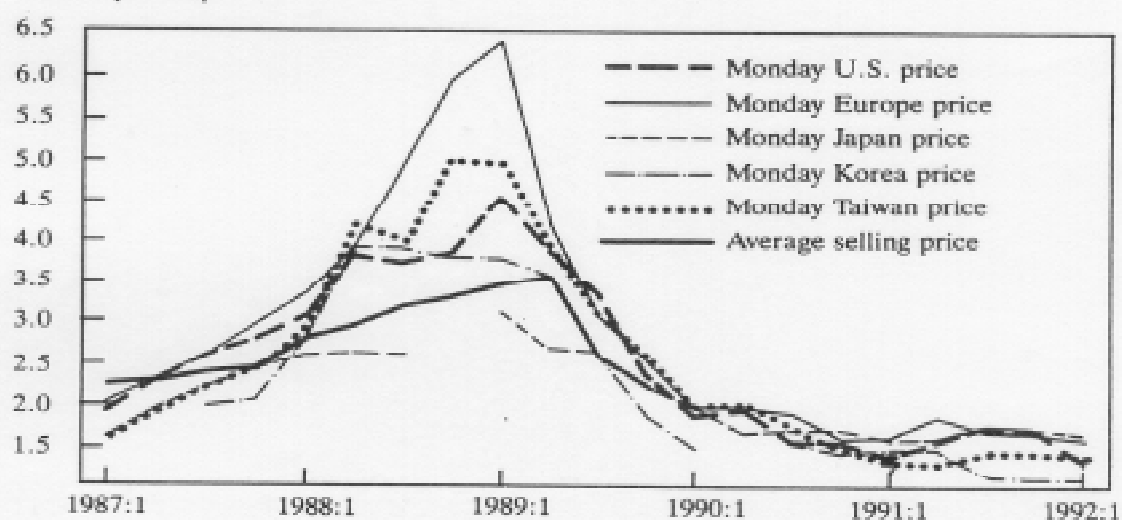


FIGURE 17. Location of semiconductor fabrication facilities in the United States, 1991.



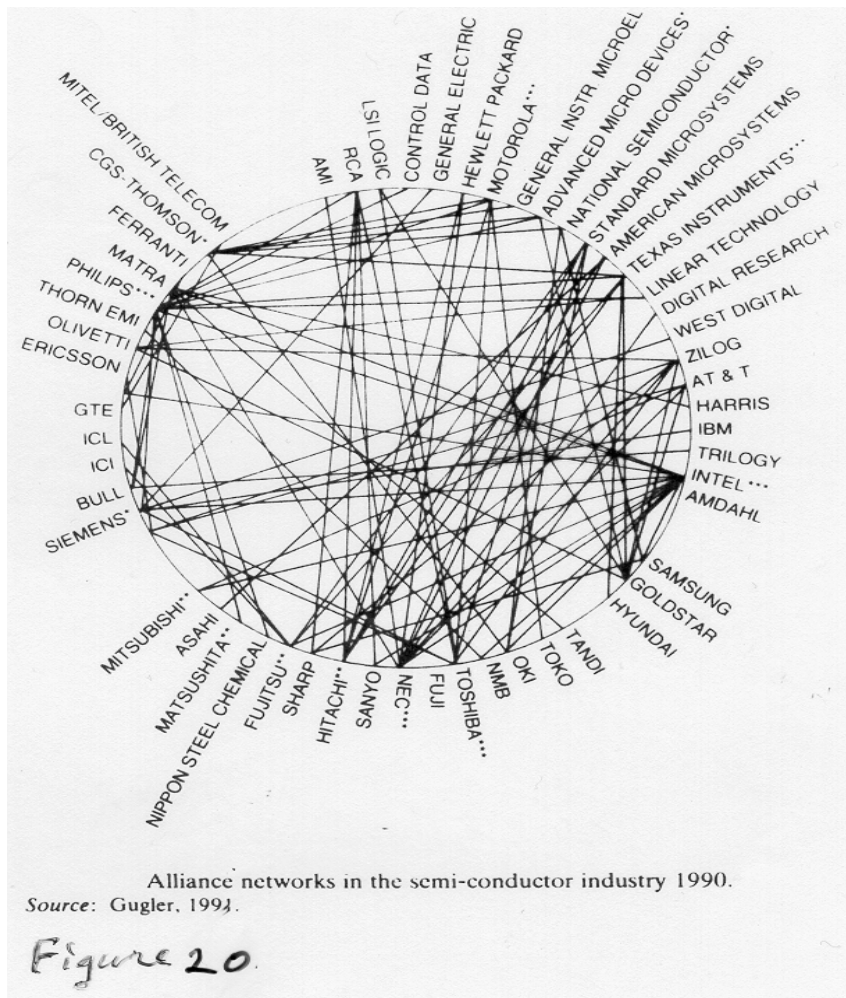
Quarterly Dataquest Monday Contract Prices and Average Selling Prices for 256K DRAMs, 1987-92^a

Dollars per chip

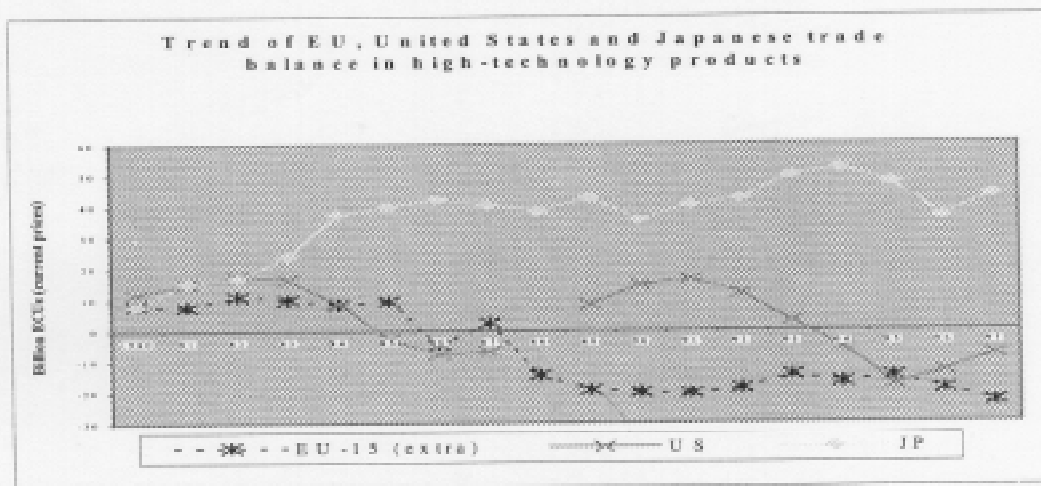


Sources: Author's calculations based on unpublished Dataquest data; and Dataquest "DQ First Monday Report."
a. Figures are quarterly averages.

Figure 19.



The European Union deficit of foreign trade in high-technology products has been worsening since 1987



Source: Research DG, Eurostat, Key Figures in S&T, 1999

Figure 21

